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HEATING SYSTEM DECISION: A STUDY BASED ON NEWLY BUILT DETACHED HOUSES IN FINLAND

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Abstract

This study examines new detached house owners’ residential heating system choice determinants in Finland. The randomly drawn survey-based research includes three separate interrelated empirical models. An overview of Finnish household space heating is included. Residential space heating system is a long-term investment, and the sector forms a significant part of energy consumption. The theoretical framework builds on the random utility theory and discrete choice models. With binomial logit formulations, we study the factors that impact the ground source heat pump adoption and the determinants to acquire innovative supplementary heating systems. Study of the primary heating system choice determinants among five distinct alternative categories is done with a multinomial logit model. The dependent variables are actual heating system choices. The survey design gives us the chance to observe stated preferences as explanatory variables.

We discover substantial heterogeneity in consumer preferences. There are statistically significant explanatory variables related to socio-demographics, house-type, the geographical area and heating system specific factors. Variable cost is the largest driver for ground source heat pump selection. Other issues that have a considerable impact are system comfort, larger home, self-sufficiency requirement and expert opinions. Innovative supplementary heating system as a part of hybrid generation can create significant efficiency gains. The determinants to acquire such system suggest the desire to remain interconnected with the grid, whereas investment cost can hinder the adoption. Energy performance certificate seems to drive the air-source heat pump choice. It appears that impacting variable price expectations could alter heating system choice. The multinomial analysis implies to cost and comfort considerations having a bigger impact than environmental attitudes. Post-decision satisfaction comments suggest a considerable need for system function check-up including the settings, especially for the heat pumps.

Keywords

discrete choice, ground source heat pump, residential space heating, supplementary heating system

Additional information

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1 INTRODUCTION

Residential space heating is used in raising the temperature of an inhabited building. When a new house is being built, there is a wide selection of heating mode possibilities with different characteristics. The heating mode choice impacts energy consumption levels and by extension greenhouse gas emissions. Costs apply both to the individual and for the entire society. Furthermore, the system affects living comfort and health. (Motiva, 2019.)

The European Commission (2016) has introduced its EU-wide strategy for heating and cooling. The strategy is expected to be a framework for future legislation. The Commission urges making efficient heating and cooling market a priority. It notes that big gains can be made immediately, provided that the consumers have the means to make the proper investments. About 70% of the EU-population lives in privately owned buildings. Many of them may lack the knowledge or incentives to make efficient investments.

Finland is committed to EU 2030 targets on climate and energy. So far it looks like we are on our way to meet them. The heating sector is seemingly the most crucial component that may hinder the progress. Nordic Energy Technology Perspectives 2016 report (International Energy Agency (IEA), 2016) presents a case study on reaching the 2°C global warming target and carbon-neutral energy system. It coins the need for an average improvement of 2.5% in the entire Nordic residential space heating sector annually until 2050. When a new house gets built with a new heating system or an existing heating-system is replaced with a new one, a long-term heating decision is done. A wrong decision could lock in a non-efficient heating system with lesser energy savings potential for decades. In that case, the emissions of the existing stock are also slower to come down and targets become harder to meet. (Hecher, Hatzl, Knoeri & Posch, 2017.)

Mounting evidence provided in the Intergovernmental Panel on Climate Change (IPCC) (2018) report suggests that it is not enough even if we have a clear path to clean production, we should speed up getting there. In studying the determinants of household space heating choice, we aim to provide information on factors that can drive the adoption of climate-friendly solutions. There is considerable energy savings potential in new innovative heating solutions and hybrid heating methods where more than one complementary heating systems are used in a way that maximizes their potential. A better understanding of the actual decision-making process can be used as a guide to finding methods towards cleaner and more energy efficient space heating sector. (Ruokamo, 2016.)

In this thesis, the focus is on the determinants of innovative space heating choices made by households in newly built Finnish detached houses. Our unique dataset gives the tools to study three separate closely interrelated research questions. We ask, which factors impact a households' primary heating system choice? Separately, we focus on what makes a household to choose a ground source heat pump. In a novel formulation, we study the discretionary decision to add an innovative supplementary heating system.

Our analysis is based on discrete choice framework. The econometric analysis is done with binomial and multinomial logit models. In binomial analyses, we examine the determinants of ground source heat pump choice and the determinants of innovative supplementary heating system selection. Ground source heat pumps are currently the most frequent and arguably the most energy-efficient heating mode in the market for new Finnish detached houses. We noted that hybrid generation increases effectiveness and requires one or more supplementary heating systems.

The multinomial logit analysis of primary heating system choice gives valuable insight into different inhabitant profiles. Evidence from Germany notes, that heterogeneity of homeowners should be considered when drafting policy measures targeting residential heating systems (Michelsen & Madlener, 2012, p. 1281). Our research implies significant heterogeneity among decision makers. We learn about the relative importance of different explanatory factors. This allows us to shed light on whether there can be targeted policies. Selecting an environmentally inefficient system may be due to pollution externalities not being properly priced. Other possibilities include credit market constraints or limited attention to operating costs as pointed by Sahari (2017). Consumers may desire a smoother operation or other system-specific factors. For all these reasons, it is highly relevant to get individual-level knowledge on the choice determinants. We can combine stated consumer preferences on things like environmental friendliness with demographic, spatial and house specific factors. Our research contributes to a better understanding to tackle the issue. The lessons learned here can be generalized under comparable conditions. (Michelsen & Madlener, 2012.)

We get information on the effectiveness of policy tools that are in place. These include if the energy performance label is associated with the heating system choice. One policy suggestion is the electrification of the heating system. Heat pumps run on electricity and could enable further efficiency gains. The less energy we use, the less we strain the electricity generation. (Strategic Energy Technologies Information System, 2016.) Our study gives insights into the choice between pumps and direct electric generation. Based on electricity price rise expectations, we can infer what could happen if we impact consumers' expectations of future variable costs. Another policy tool to make the heating market more effective is to have all market participants take part. (Ellsworth-Krebs & Reid, 2016). The European Commission (2016) urges active participation from consumers and industries. Choice determinants knowledge can help inferences on what matters would drive the adoption of systems, which could enable market participation.

The results of this study can also be used by manufacturers and suppliers for product development. Companies selling heating systems may also gain insights. The study provides details on most efficient impact channels, barriers of sale and post-sales support needs.

The research is structured as follows. Chapter 2 presents a brief literature review. It is followed by an overview of the residential space heating as a part of the Finnish energy market in chapter 3. The theoretical framework is given in chapter 4. In chapter 5 we introduce the data and the variables crafted on that basis. Chapter 6 will report the results of the analysis. We start with the binary choice of the ground source heat pump in section 6.1. We show some cost considerations impact the ability of the people to choose this system. In the following section 6.2, we present a supplementary heating system regression. This unique formulation suggests an intriguing interconnected profile for the people who choose to invest in an additional heating system. Section 6.3 presents the multinomial choice analysis results for the primary heating system. Following the multinomial logit model results, we also briefly touch on the post-decision satisfaction based on the survey answers. Conclusions come in chapter 7.

2 LITERATURE REVIEW

Dubin and McFadden (1984) have laid the foundation for the analysis of heating system choice impacts. They isolate the effects of space and water heating system choice in order to analyse household demand for electricity in a discrete-continuous choice approach. Two prominent examples of this approach with Nordic data are by Vaage (2000) and Nesbakken (2001).

Michelsen and Madlener (2012) conclude that most of the established research in the field is to use demographic and socioeconomic variables to explain space heating decision concerning either several alternatives or a single space heating solution. Further explanatory variables include spatial issues such as the administrative area and system-linked variables like the fuel price of the heating system in question. Such revealed preference data is obtained either through surveys or from national registries and does not inspect attitudes (Michelsen & Madlener, 2013).

More recently behavioural research including attitudes and preferences has become topical. Many studies on this field deal with choices of innovative space heating systems and follow the diffusion of innovations theory of Rogers (2003). (Michelsen & Madlener, 2013.) An example of this from Hecher et al. (2017) conjures a conceptual model combining the approaches of Mintzberg (1976), Rogers and Michelsen and Madlener (2010) for a three-stage decision making process. Another branch of research uses hypothetical data, either surveys of possible decisions or stated preferences studies to analyse the adoption choices. Research that combines stated and revealed preference variables is rarer. (Karytsas & Theodoropoulou, 2014.)

In a combinatory approach, Michelsen and Madlener (2012) conduct a discrete choice analysis with German data on innovative residential heating systems preferences. They perform the analysis using a multinomial logit model and explain the heating system choice by socio-demographic, home-specific, location-specific and heating system specific variables combining both stated and revealed preferences in an approach similar to ours. Their sample is restricted to those homeowners who had chosen at least partially renewables-based residential heating system. According to Karytsas and Theodoropoulou (2014), this is the standard convention in the field.

A fair number of singular heating system determinants studies can be found. For the ground source heat pump, there is an intent to adopt study from Greece by Karytsas and Theodoropoulou (2014). Supplementary heating system studies combining more than one system have not been done to our knowledge. A solar thermal heating system intention to adopt study by Woersdorfer and Kaus (2011) is from Germany. The online survey in Norway by Lillemo, Aldnes, Halvorsen and Wik (2013) study the determinants of four heating system including air-to-air heat pumps. Scarpa and Willis (2010) consider both the primary and supplementary heating system choices of British households with a choice experiment.

There has been some research interest in the Finnish residential heating too. Using the same survey data as we do, Ruokamo (2016) analyses household preferences for hybrid heating systems with a choice experiment. Furthermore, Karytsas and Theodoropoulou (2014) list a pellet heating adoption study by Tapaninen, Seppänen and Mäkinen (2009), a stated preference study by Rouvinen and Matero (2012) and finally, a multinomial logit model of heating system choice by Kasanen and Lakshmanan (1989) as examples of studies done in Finland on the matter. Doctoral dissertation from Kasanen (1990) focuses on heating system and fuel choices. Additionally, there is a master's thesis from Pippuri (2012), who applies multinomial logit and binomial logit regression on heating mode choice and socioeconomic data of 1260 households to study whether consumers who built a detached house in Finland in 2008 overweigh initial costs vs lifetime costs of a heating system. The study finds no conclusive evidence overall but some insights for specific heating systems being preferred by different income groups.

Asplund (1984) estimates the role of electricity price changes to the use of electric heating in Finland from 1975–1982 with a dynamic flow-adjusted model. Far greater long-run than short-run elasticity of demand shows the price impacts customers' electric heating equipment stock investments. Sahari's (2017) doctoral thesis uses administrative registry and RTS Rakennus Oy -corporation collected data with a random sample covering over 109 289 observations on households that built a new home in between 2000–2011, corresponding to around 90% of the houses built during that period in Finland. She focuses on the impact of electricity prices and other factors on household investment decisions. There is considerable heterogeneity between households in valuing future energy costs and initial investment costs. Higher income households are willing to pay more upfront whereas lower income household may be constrained to have to choose a heating method that is cheaper upfront but more expensive in the long run implicating capital market inefficiencies. In subsequent publication covering the first article, Sahari (2019) finds evidence that distribution price shifts induce substitution from and to electric heating.

It would also be possible to apply multi-criteria decision analysis for heating system choice before it is made. An example of this from Finland is done by Kontu, Rinne, Olkkonen, Lahdelma and Salminen (2014), who conduct an evaluation of the preferred heating method choice for a new sustainable residential area in Loviisa, Finland based on 15 criteria. They assume a new 180 m^2 house with three inhabitants. The final selection criteria include investment and operating costs, environmental impact, various social issues as well as technical and usability related matters. They start the study with a small survey to gauge the preferences of experts and potential inhabitants. The survey results inform the researchers which kind of issues should account for local conditions. A policy recommendation is crafted on this basis. The researchers conclude biomass-fuelled combined heat-power plant district heating network and ground source heat pumps to be the preferred options. On the other hand, the viability of solar-based supplementary heating solutions is strongly questioned.

We also have several undergraduate thesis-level case analyses from other disciplines, that also give a detailed explanation of local conditions and practical issues that arise in heating system choice. These are often motivated by the family need for a new system and may be calculated for a single house in question. Recent examples of these include Roivainen (2012), Ollikainen (2014), Pyykkönen (2014), Kärkkäinen (2015) and Toppinen (2016). All of them include a lifetime cost calculation of the systems under selection criteria and for that purpose, they have mainly utilized public sector sustainable development information company Motiva's (2018) comparison calculator for the heating options of detached houses. The comparison calculator is freely accessible online.

3 HOUSEHOLD SPACE HEATING IN FINLAND

The following chapter is intended to give the reader a general understanding of the market context we are dealing with. Description of our markets, resources, geographical realities and technical description of currently available heating systems adds context for our analysis.

3.1 Sector impact

Finland has more than 300 000 m^2 of land, north-south distance of over 1100 kilometres and is mostly sparsely populated with just around 5.5 million inhabitants. Most of Finland has subarctic climate conditions, with the entire country excluding the very southernmost parts belonging to Dfc in Köppen-Geiger climate classification (Peel, Finlayson & McMahon, 2007). Winter is the longest season, which means our space heating needs are elevated. (Official Statistics Finland (OSF), 2019.)

In Table 1 we have summarized the magnitude of residential space heating sector in Finnish energy consumption. The share of residential space heating (RSH) accounted for around two thirds out of total household energy consumption all through the 2010s. This is more than double the 32% share in the world reached in 2010 according to IEA (2012) as cited by Ürge-Vorsatz, Cabeza, Serrano, Barreneche and Petrichenko (2015). The difference can be attributed to the colder climate and is only partially mitigated by improved energy standards of buildings in Finland. Energy consumption in households covers slightly under 20 per cent of total energy consumption in Finland. Note that this represents only the in-house consumption. For instance, private households also contribute to total energy consumption via traffic. As can be noted from Table 1, the share of residential space heating reached double-digits during the entire 2010s. Domestic water heating is normally done with the same system as space heating. Its share has been slightly below 10 TWh[1], every year all through the decade.

[1] The units of energy in joules and Gigawatt hour power units are converted to a measurement of power Terawatt hour (TWh, = 1 000 000 000 kWh). Residential housing energy covers space, water and sauna heating energy and household appliances energy use.

If we add domestic water heating to the residential space heating, we would be above 80% for household consumption and between 13–14% out of total energy consumption. (OSF, 2019c.)

Table 1. Residential space heating (RSH) share of Finnish energy consumption.

End use in TWh or %	2010	2011	2012	2013	2014	2015	2016	2017
Total energy consumption	408	387	382	383	375	364	377	374
Residential housing energy	70	62	67	63	64	61	67	66
Residential space heating	49	41	46	43	43	41	46	45
Domestic water heating	10	10	10	10	10	10	10	10
Housing of total energy %	17 %	16 %	18 %	16 %	17 %	17 %	18 %	18 %
RSH of total residential %	70 %	68 %	68 %	67 %	67 %	66 %	68 %	68 %
RSH of total energy %	12%	11%	12%	11%	11%	11%	12%	12%

Source: Official Statistics of Finland (OSF, 2019c)

Housing is the primary household greenhouse-gas emission source. The combined share of commercial electricity and heat production is responsible for around a third of total emissions. (OSF, 2019c.)

The financial implications of the sector are enormous. In 2017 Finland's energy imports totalled 8.8 billion euros. The exports were worth 4.78 billion. (OSF, 2019.) European Commission (2016) estimates that the European Union could save nearly 45 billion euros annually by moving from fossil fuels to a decarbonized building stock using local renewable energy heating and cooling solutions.

The energy-use differences are largely stemming from different systems. It thus becomes clear how much can be done by targeting space heating through energy policy and how important it is that the right kind of decisions are made on aggregate. Despite their large scale, heating markets common regulation is still missing from the EU. (European Commission, 2016.)

Furthermore, from an individual utility maximization viewpoint, comfort in one's own house is seemingly a major component of wellbeing. Properly functioning space heating is crucial for the health of the occupants; both directly and by way of maintaining the health of the building structure itself. In fact, the European Commission (2016) notes that 11% of European Union residents could not afford to keep their house warm enough in the winter. Not only is this a matter of comfort, but health and efficiency as well. The Land Use and Building Act (1999) stipulates that the entity undertaking a construction must make sure that the structure is built to be healthy and safe taking into consideration the inside air quality, temperature and lighting as well as the water supply.

As a significant part of consumption, space heating also plays a central role in the electricity market functioning. In EU strategy for heating and cooling (European Commission, 2016), the Commission called for better synergy of the heating and cooling markets with the electricity grid as the latter shifts to a more renewables-based system. Linking the heating market with the demand management could conceivably generate efficiencies that would help both the consumers and the society. Therefore, we also briefly discuss the linkages of these markets.

There are components within energy use that have come down as a result of technological innovations. One good example is lighting where the shift to Led-based technologies is clearly visible from national energy consumption accounts. The share of heating has been remarkably stable. (OSF, 2019c.) Even though cleaner generation methods do exist, fossil fuels continue to play a role as can be seen from section 3.2.

3.2 Natural resources, markets and environmental impacts

Finland is resource rich with wood and peat that can be utilized for energy generation. There are an estimated 30 billion cubic metres of commercially feasible peat resources, out of which about 24 billion m^3 in the type of peat that could be used in energy generation. Peat is used in district heat generation, and peat pellets can fuel pellet heating. The peat reserves contain an estimated 13 000 TWh of energy or about 10-times the standing stock of wood. (Geologian tutkimuskeskus, 2019.) It is therefore easy to see why there have been times when increased domestic use of this resource has been on the political agenda (Kasanen, 1990, p. 5). Peat, however, regenerates very slowly within thousands of years, is a substantial carbon sink and might be even less carbon efficient fuel source than fossil fuels (Murphy, Devlin & McDonnell, 2015). In collaborative research spearheaded by Finnish Environment Institute SYKE, Seppälä et al. (2010) conclude that after-treatment activities such as forestation of the swamp could only partially compensate for the emission over a 100-year perspective. They write that the environmental impact at that point is roughly equal to burning coal. This fact seems to have turned the tide against peat for energy, leading even the public producer Vapo to prepare for its lessening impact (Yle, 2018).

The story is different when it comes to utilizing our timber. Finland has a 2500 million cubic metre forest resource (LUKE, 2018a). The trees cover about 70% of the land with over 20 million hectares fit for wood production. Finland’s annual forest growth is over 100 million cubic metres, and it has maintained well above the stable growth rate. The 2017 growth of 107 million m^3 could be compared with 87 million m^3 drain. Log and pulpwood account for 63.3 million cubic metres of the 2017 drain. The rest includes natural causes, firewood, and other domestic uses as well as logging residues and the energy wood. (LUKE, 2018b.) The use of wood in energy generation is estimated based on surveys. Official Statistics of Finland and National Resources Institute Finland Luonnonvarakeskus conducted the most recent extensive research of small-scale wood use for the 2016-2017 season. Such studies have been done around once a decade, with the one before that for the 2007-2008 season. In 2017, wood-based fuels accounted for 27% of total energy consumption (OSF, 2019c).

Around 60% of the total forest resources in Finland are privately owned. When we include joint ownership, there are some 632 000 forest owners. They represent a total of almost 12% of the entire population. (Finnish Forest Association, 2019.) Eastern and Northern Finland have relatively larger proportion of government-owned forests. In Southern and Central Finland private ownership is the norm, with about three-quarters of local forest land owned by the private sector. (Ministry of Agriculture and Forestry of Finland, 2019.) Finnish National Forest Inventory is a uniquely extensive resource enabling accurate follow-up of forest management trends and growth. With more forest growth than loss, there are no net carbon emissions. Calculated in this manner wood is classified as a renewable resource. (LUKE, 2018b.)

While wood in Finland is deemed a renewable resource, its small-scale use is not without environmental problems. Ministry of the Environment report 16/2016 as written by Hänninen, Korhonen, Lehtomäki, Asikainen and Rumrich (2016) estimates around 1600 premature deaths in Finland per year to be a result of air pollution. Small-particle emissions are a major contributor. A 2010 risk assessment report from THL, the National Institute for Health and Welfare (Terveyden ja hyvinvoinnin laitos, 2010) estimated 250 deaths annually to be a result of wood burning for residential space heating. Small-scale burning of wood accounts for around 46% of total small-particle or $PM_{2.5}$ emissions in Finland (Suoheimo et. al., 2015). Its relative importance is expected to grow since, despite ongoing discussions about the matter, there is no upcoming regulation in sight. At the same time, other sectors such as industry and traffic face tightening regulation. In addition to this, small-scale burning is responsible for 55% of black carbon emissions, over 80% of the polycyclic aromatic hydrocarbons compound PAH emissions, around 30% of the volatile organic compound VOC emissions and 25% of carbon monoxide emissions (THL, 2019).

Most of the available space heating solutions use electricity. Only in wood and fossil-fuel-based systems and in district heat its contribution is minimal. The Finnish electricity network is quickly changing to a more renewables-based system. Perhaps the biggest challenge for integrating renewable energy is peak-demand management. Space heating is a noteworthy contributor to peak demand in Finland. Our peak consumption happens during cold winter days. In a high-pressure system, small particle emissions also linger. A further complication is that Finnish solar energy generation potential is minimal in January. (Finnish Energy, 2019a.)

Wind power already plays a sizeable role in Finnish electricity generation. According to VTT (2015), the technical research centre of Finland, around 60% of Finnish wind power has been generated in the winter months. While this shows that wind power generation is generally highly synergistic with larger potential in the winter months than in the summer, a January high pressure bringing extreme cold coupled with calm conditions could still be problematic. (Toivanen et al., 2017.) We could use more interdisciplinary research to match the coldest December-March wind condition patterns and peak electricity demand with corresponding wind power generation readings and estimates for higher future production levels. Using Fingrid (2019) wind power generation tool, for instance in January 2019, wind power generation ranged from above 1700 MW to mere 34 MW. Similar intermittency but with lower peaks can be observed during the icy cold latter part of the month. Selecting the most energy efficient residential heating system will lessen the need for reserve capacity, and relatively more so in the peak demand conditions.

The Nordic Pool enables trading of electricity across country lines. Our electricity imports were 22.2 TWh or 26% of the total electricity consumption while exports were a mere 1.8TWh or 2.1% of consumption in 2018. There has been a rising trend through the 2010ies in Finnish electricity imports. The trend is accentuated by the delays in construction of Olkiluoto 3 nuclear power plant, which was supposed to enter production by 2010 but at the time of this report looks to come online in 2020 at the earliest. (OSF, 2019b.)

The difference between the space heating energy produced by heat pumps and the electricity used in its consumption is called ambient energy (Official Statistics of Finland, 2019a). Ambient energy is inexhaustible stored solar heat and can be harvested from the ground, sea or air. The rise of it in Finnish energy generation is particularly noteworthy, up from 1.5% to 7% within the last decade. The remaining part of total residential, commercial and public sector heating in 2016 was produced 40% with district heat, 21% with electricity which includes the electricity needed in running ambient generation, 21% with wood, and 8% with light fuel oil. All other sources had a negligible impact. (OSF, 2019b.)

For detached houses, the residential heating including saunas and heating of domestic water was over 120 000 TJ or over 33 TWh in 2016. Sauna heating spent around 3 TWh of it and domestic water heating about 10 TWh. This leaves about 20TWh for space heating alone. The energy for the total 33 TWh consumption was generated as follows: 39% wood, 9.2% oil, 13.9% ambient energy, 31% electricity and 6.9% with district heat. Electricity spent by ambient energy generation is once more included in the share of electricity. (OSF, 2019b.)

Following a press release from Finland’s heat pump association, Suomen Lämpöpumppuyhdistys (2019), it was widely quoted in the media that already 900 000 heat pumps have been sold in Finland by 2019. The release also highlights that they produce 15% of residential and commercial stock energy. One should bear in mind that this number refers to net effective heating energy and includes the portion of electricity demanded by the pumps. The thermal efficiency estimate was not made available, but anecdotally it would seem that the net number is in low double-digits and thus higher than the 7% in energy sources. It would seem to indicate better efficiency compared to the entire production mix in aggregate.

District heating is the most popular heating solution if all buildings are included (OSF, 2019b). Nearly half of our heating energy is district heat. The district heating network covers 166 cities and towns. (Motiva, 2019.) Energiateollisuus [Finnish Energy] (2018a), the advocacy group representing the Finnish energy industry that is responsible for disseminating and supplying this information to Official Statistics of Finland, calculated that 35% of district heat is produced with fossil fuels and less than half is carbon neutral. Wood-based fuels produce around a third of district heat. In 2017, other notable contributors were coal with 23%, peat 14%, natural gas 10%, waste heat around 9% and other biomass some 7% of the total production of 36.6 TWh. The debate concerning cleaning the district heating generation system is now raging. Just within the past few months, we have heard suggestions for major wind investments or large heat pumps (Rinne, Auvinen, Reda, Ruggiero & Temmes, 2018). Even small-modular reactors, “mini nuclear-plants”, have been suggested (Tulkki, Pursiheimo & Lindroos, 2017).

3.3 Heating system shares and lifetime cost example

Figure 1 shows residential heating system (RHS) market shares in detached houses. The continuous rise of ground source heat pump is the most notable change. Its share in new detached houses has grown steadily from under 30% in 2006 to approximately half at the time of this thesis, making it the by far most popular heating system choice for new detached houses. The share of district heating and pellet heating have continued to come down slowly. Air-to-water heat pump has continued to gain market share. There are rather large yearly fluctuations in other systems.

In addition to the ones we cover below, fossil fuels including natural gas and oil also maintain a minor share for new houses and a slightly bigger portion of system replacements. As of 2016, we had an estimated 200 000 single-family houses heated with oil. With oil prices remaining relatively low, incentives for quick replacement of existing system do not exist unless policy actions are taken (Hast, Ekholm & Syri, 2016). The natural gas network in Finland only extends from Russian border near Imatra to Helsinki and Tampere and is not widely available for households. Gas power production does play a role, especially as reserve power that can be brought to the grid quickly during forecasted peak demand. (Ministry of Economic Affairs and Employment of Finland, 2019).

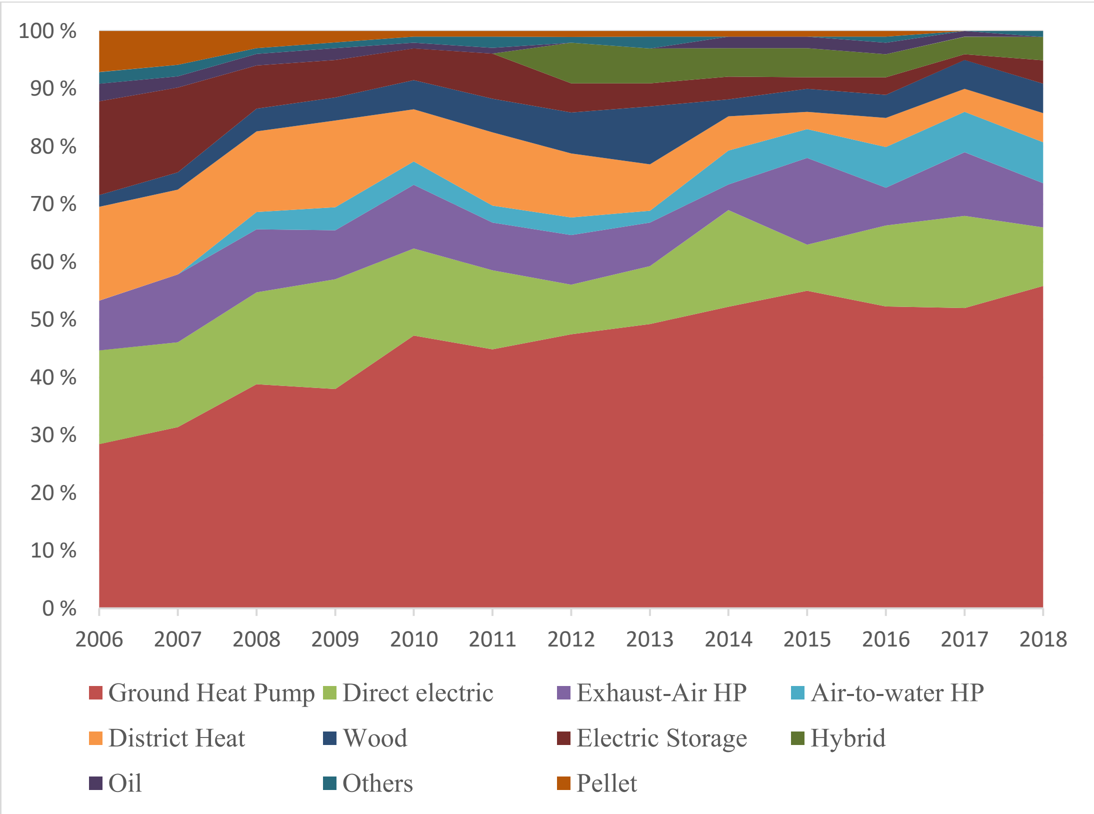

Figure 1. RHS in Finnish new detached houses 2006-2018 (adapted from Motiva, 2019).

Hybrid generation combining two or more primary heating solutions exist. There are also potential investments in renewable biofuel and biomass, both of which might provide options for space heating. Our research also includes several supplementary heating systems that can augment or acts as a backup heating system in case of system failure. (Motiva, 2019.) In 2017, there were on average two heating systems per house.

Regarding the supplementary heating systems, most often it is a fireplace or baking oven or both. An outside air heat pump was installed into 7% of new houses. Out of these, the last one is such a system that can often be installed afterwards without major modifications. (Rakennustutkimus Ltd, 2018.)

A low-income household in need of a heating system renewal for an old house could enjoy a grant from 2008–2016 (KSML, 2016). All the households are still able to claim up to a 2400-euro tax deduction per person for installation costs incurred during a system change (Finlex, 1997). This so-called domestic help credit is relevant when you are changing a heating system for an old home. As an example, when you install a ground source heat pump to an old house, it is possible to get a tax rebate that is not only relevant to the installation of the machine but also for the borehole drilling. Same is true for the construction needed on the yard for district heating pipe installation. Generally, the credit can be used for the portion of the actual installation work of any such renovation deemed important. However, for new houses, no such rebate exists. (Finlex, 1997.)

For a short illustration of the costs of different heating systems in a new house, we utilized Motiva's (2018) comparison calculator for the heating options of detached houses for two types of houses, a 100 square metre passive house in southern Finland and a 150 metre 2010 energy standard house in Lapland. In case one, the estimated total heating energy requirement is 4920 kWh/year and in case two 24589 kWh/year. The calculator is widely used, and we test its stated impact on heating system choice as one variable in our logit analysis runs. It is sensitive to assumptions about the investment costs, energy prices and interest rate level. We examine only the primary heating system choice. Exhaust-air heat pump and air-to-water heat pump options alone are not available for the Lapland house. If we were to add supplementary systems to those pumps, their combined annual costs for option two would place them at around 2770 euros or around 42000 euros for the whole period. The cost distribution of this experiment is given below in table 2.

Table 2. Primary heating system cost profiles example.

Heating system	Investment (€)	Var. Cost (€)	Annual TC (€)	15 year TC (€)
Ground Heat	15300	**240–325**	1412–1490	21732
	15300	**1221–1661**	**2388–2778**	**38614**
Pellet	12240	340	1272	19071
	12240	1680	2614	39201
Air-To-Water HP	10000	430–570	1204–1304	19032
	N/A	N/A	N/A	N/A
Exhaust-Air HP	10000	430–570	1206–1342	19058
	N/A	N/A	N/A	N/A
Oil	8170	630	1254	18810
	8170	3200	3774	56610
Dir. electric	**4080**	700–950	1027–1255	17037
	4080	3576–4719	3887–5029	66496
District heating	7650	490	**1076**	**16128**
	7650	2458	3042	45618

Above: 100m2 passive house occupied by 3 inhabitants located in southern Finland with 2.4 m room height.
Below: 150 m^2 2010-standard energy level house housing 4 people with 2.8m room height in Northern Finland.
Cheapest option bolded, most expensive underlined.
Figures based on Motiva Ltd energy calculator (Motiva, 2018), contains assumptions of system efficiency, heating fuel costs, discount rates and investment costs.

A ground source heat pump is generally the most expensive option with the costs for a new house in Finland varying from around 12 000–22 000€. The variable costs are the lowest, for the pump uses only around a third of the electricity of electric heating. Electric heating is the cheapest to install and usually the most expensive to run. Other systems fall in between these extremes. (Motiva, 2019.)

3.4 Technical description of heating systems

New detached houses in Finland are now most often fitted with a water-circulating space heating solution. Heated water circulates primarily in wall-batteries or under the floor. It is also possible to use dry solutions, which are mainly air- or structure-heating systems. In our survey, approximately a third of the respondents found selecting the heating system of the new detached house to be complicated. The cost of the system is only one part of the equation. In the following, we will briefly introduce the technical characteristics of the main options currently available in the sector. (Energiatehokaskoti.fi, 2019.)

A ground source heat pump uses electricity to run and to convert geothermal heat or solar heat that has been stored in the ground or the water into heating energy. The heat collection can be done with a borehole or horizontal piping on the ground or under water. In the case of the borehole, much of the energy collected is geothermal meaning it originates from fission reaction in the core of earth. Ground source heat pump is not viable for every plot of land and may not always get a permit. (Motiva, 2019.)

We have two other heat-pump technologies that are often used as the primary heating system. An exhaust-air heat pump runs with electricity and extracts heat from the exhaust air of the house and moves it to incoming fresh air. It dual-functions as a ventilation system. System maintenance is mainly occasional filter replacement. An air-to-water heat pump takes heat from outside air into circulating water. When the outside temperature falls low enough for an extended period, to around -20 °C, some additional heating is required in both systems. Resistors fitted into the system can fulfil this purpose. Wood as an additional source of heat during the coldest season improves calculated efficiency. One should make sure that the wood heating system can operate in conjoint with the pump type. Both pump systems require the proper size system to run efficiently. (Motiva, 2019.)

We will use the wording direct electric (heating) to describe a room-specific solution containing an electric radiator or a heater. These days a dry-solution is prevalent. Electric heating is generally the cheapest option to install and the most expensive to use. Each room heater typically has a thermostat which allows room-specific temperature control and quick adjustments. (Energiatehokaskoti.fi, 2019). Electric storage heating uses an accumulator to store heat when base load energy is available cheaply. The difference between nighttime and daytime electricity prices has come down considerably. Its impact is even further lessened by the distribution price becoming an even larger component of the electricity bill. Pahkala, Uimonen and Väre (2018) suggest big changes toward a more dynamic system for the time-of-day and seasonal load management in the Smart Grid Working Group final report. When we move towards more intermittent generation, and market mechanisms and consumption automation technology mature, it is conceivable that it may become wise to use accumulation whenever there is ample and cheap generation available. Both direct electric and electric storage heating are easy to use and rarely need maintenance.

District heating generation is a centralized solution most often produced in one site. Thermal energy stored in hot water is led to customers through a circular network of insulated piping. The heat is released into the houses through heat exchanges located in a district heating substation. This substation may serve a block, a group of houses or a single detached house. It also means that the district heating network water itself does not circulate in the buildings. It is typically used for both space heating and domestic water heating purposes. (Finnish Energy, 2019b.) Generally, for an end user, the system is relatively maintenance free yet rigid when it comes to temperature control. While there are pilot projects for the utilization of return-side of the district heating network, it will be difficult for consumers to partake in any market schemes, unless we are talking some in-block arrangements. (Koskelainen, Nuorkivi, Saarela & Sipilä, 2016.)

In new urban areas, joining district heating network is usually a regulated possibility, for old areas you will need to solicit an offer from the local energy utility. The offered price depends on pipe length and estimated consumption (Teknologiateollisuus, 2019b). Furthermore, as the network grows longer the efficiency losses increase across the entire grid. On a citywide level, district heating network cannot be turned off easily. The investment for urban planner is very long-term. With a mature network that is not expected to grow much, the network owner has incentives to hike the price. While a comparable natural monopoly, similar regulation like we have in electricity transmission typically does not exist. Price visibility for an individual consumer is therefore much lower. (Li, Sun, Zhang & Wallin, 2015.)

Land Use and Building Act (1999) was amended from the start of 2009 with the 57 a § giving municipalities the chance to regulate in the city/town plan that a building needs to join district heating network. The law coincides with the duration of our study. However, only an estimated 10-20 municipalities had implemented such regulation by 2017. Furthermore, the Act stipulated that such regulation does not apply to a building with a maximum of 60% heat loss of that of a comparable building. The Act also did not cover building repairs and maintenance and, most importantly for this study, a building project that installs renewable energy based low-emission heating system. This regulation was abolished in 2018. In addition to the negligible impact it had had, the government cites the desire to increase competition in the sector. (HE 79/2018 vp.)

We highlighted Finland's vast forest resources in the preceding sections. As a primary heating system, a house warms as either regular firewood, chopped wood or woodchips are put into a wood boiler to burn and release heat. Conventional heat distribution system is a water-circulating battery or floor heating piping. An accumulator for heat storing is often present. In order to burn cleanly and efficiently, the wood fuel must be dry. Proper drying takes up to a year unless a commercial facility is used. The type of boiler and wood decide how often fuel needs to be added. This action is usually done manually. At the very most, one load may last up to one day. Some additional maintenance is also required making the system by far the most labour-intensive of the available heating modes. (Motiva, 2019.)

Firewood contains the least amount of energy per unit of volume of all the fuels discussed here. That means that all else equal it requires more storage space. The space need can be less if you buy your wood and do it frequently. You could store firewood on your plot of land if you cover them. Woodchips and chopped wood can be cold-stored in a warehouse. For wood, there is no similar uncertainty over future costs if you can get it from your land. Since waste wood has very little commercial use, in that case we just care about the opportunity cost. If you own the forest, you may at the same time be doing valuable forest management tasks, in which case the opportunity cost could even be negative. The social cost of wood burning may be higher in a more densely populated neighbourhood. (Energiatehokas koti, 2019.)

Pellet heating typically uses compressed wood, or with some system modifications substitute fuel such as peat or oat. The wood pellets are mainly a by-product of the sawmill industry. This indicates a relatively stable and abundant supply with relatively good price visibility. As can be seen from table 2, pellet heating economics may be quite competitive. Despite forecast to the contrary, pellet innovation has not taken much of a market share in new detached houses. It has come down from a 6% share in 2006 to below 1% in 2018. Installation of a pellet heating solution requires additional equipment including a burn unit, silo and loading equipment. The technical room that is usually needed also must comply with local requirements. (Puhakka, Alanen, Kokkonen, Nalkki & Rousku, 2003.)

Skjevrak and Sopha (2012) study early adopter satisfaction with respect to wood pellet heating. They list that some of the early adopters had experienced noise factors, igniter failure, inappropriate combustion, control and fuel feeding system issues. The difficulty related to maintenance time seemed to be the major obstacle; automated loading was called for. More recent solutions address this issue. Other delaying factors are related to dust from varying pellet quality. Additionally, low vendor commitment has eroded market confidence for future maintenance support of pellet heating. Some suppliers have discontinued providing pellet stoves. The still maturing technology and recent low electricity prices make them conclude pellet heating share will likely not grow in Norway without innovations. Our data also contains supplementary heating systems. Their technical characteristics are beyond the scope of this study.

New policy multipliers for the environmental impact of a heating system came to force at the start of 2018. The goal of this regulation is to direct toward more efficient solutions. The less efficient the choice, the more energy efficient the building must be to be able to secure building permits. The most notable change is a significant lowering of the environmental impact of electric heating. While still maintaining the highest multiplier at 1.20, it is down from 1.70. Fossil fuels maintain multiplier of 1.00 and district heating’s multiplier comes down to 0.50 from 0.70. Renewable fuels burned in the building stay at the 0.50 level. (Valtioneuvosto, 2017.)

4 THEORETICAL FRAMEWORK

4.1 Discrete choice theory

Each time a consumer purchases a good and there are alternative ways to spend the money, a choice is made. The choice takes place as a result of some behavioural process we will attempt to explain with theory. (Train, 2009, p. 11.) A space heating system is a long-term one-off purchase. In an Ipsos Mori and the Energy Saving Trust (2013) survey, consumers expect the need to replace the heating system at the earliest after 15 years. Some of the respondents had already used their heating system for over 20 years. The 20-year cut-off is frequently thought to be a realistic assumption. Therefore, we are not dealing with a continuous demand schedule but instead with a discrete choice.

The demand for space heating system is derived from the space heating service provided by the system. (Kasanen, 1990, p.6). When we compare competing products, what we care about are the qualities of the product such as its cost and functionality. These characteristics of an alternative are called attributes in choice theory (Hensher, Rose & Greene, 2005, p.695).

Economists describe and model the benefit from the consumption of a good with the concept of utility. We will make assumptions of it and represent the utility typically with an inverse diminishing function of price over quantity demanded. An individual will then demand more of the good if the value of consuming an additional unit of the good exceeds its price. The analysis is subject to constraints such as the budget set and a positive price. A common representation is to treat other things that affect demand as if they remain constant. The demand function for the good affected by price, ceteris paribus aka other things equal, can be derived from these components. The discrete nature of the choice situation means that such basic microeconomic consumer choice theory may not be directly applicable. Instead, we will use discrete choice theory. It can answer questions such as which one will be chosen or what is the finite discrete number of purchases of an item we will make. Dependent variable indicates whether or not an event took place. (Ben-Akiva & Lerman, 1987, pp. 39–58.)

If one system in place provides adequate house temperature control, extra gain from the heating service provided by another primary heating system is assumed to be minimal. Utility of such a situation is just some $U(y) = (y_1, y_2, \dots, y_n)$ and what we are doing is maximization over this discrete set of alternatives assuming that only one of the alternatives will be chosen. The decision maker chooses the one that provides the highest level of utility. Instead of being able to differentiate a utility function and taking first order conditions to see how much will be consumed, for such a situation we need to observe the utility differences and maximize with the attributes to see which option gets chosen. The usual method for this is maximum likelihood. An intrepid reader may also note the probabilistic models we are using constitute another difference to standard microeconomic theory. The decision rule assumption is that the good providing the highest utility gets selected. However, it is argued that the researcher cannot observe all the characteristics of the utility. For this reason, assumptions are made on the probabilities of the choice and utility. (Greene, 2012 p. 723; Train, 2009, pp. 11–17.)

In modelling our choice situation further, we are dealing with a multinomial model since there are more than two options available. Tversky (1972) shows that when decision makers face multiple alternatives that have observed dependencies, they often act inconsistently. The number of available options in our choice situation is however relatively small, and we assume that the researcher and the decision maker can determine them without any initial-stage screening. Therefore, we are more confident to start our analysis with the assumption that different alternatives are independent of each other. This means that standard multinomial models are applicable (Zolfaghari, Sivakumar & Polak, 2013). Choices are mutually exclusive since only one main heating system is needed. We will assume that for $U_i > 0 \; \forall \, i$, meaning it is assumed that all viable space heating options provide positive utility. (Train, 2009, pp. 11–14.)

Let us represent the situation with an example. Assume that the consumer A is deciding between two heating systems, an electric heating (EH) and a pellet heating (PH) system. There are no other options, so we have a binary choice situation because having a heating system is mandatory. A consumer has perfect foresight and access to perfect capital markets and is not constrained by his budget set related to these two options. The consumer makes the decision based on what benefits him the most, meaning he chooses the system that provides the highest utility to him. Choosing one system implies there to be no need for the other. This means we have defined the choice situation to be complete, there are no additional options, and the alternatives exhibit mutual exclusivity. In summary, we have a decision maker A, an exclusive, exhaustive and finite choice set S = {PH, EH}. These are the conditions that a discrete choice model choice set must meet. The decision rule is based on unconstrained utility maximization. (Train, 2009, pp. 11–14.)

In order to predict the choice made, we need consumer preference knowledge and information on the attributes of the choices. We assume that only relevant attributes impacting choice are the total lifetime costs c and comfort of use m. We would also need to scale their relative impact on the utility. The utility may depend not only on differing attributes of alternatives but also on the characteristics of the decision maker A. If we ignore those here, the utility function would now take the form of $U_A = U\Big(\big(f(c_1) + g(m_1)\big), \big(f(c_2) + g(m_2)\big), \dots, \big(f(c_n) + g(m_n)\big)\Big)$, where the functions of c and m represent those attributes assumed impact on utility. Assuming perfect foresight and rational decision maker in each case, once we know the cost of the systems and the lifetime monetary value placed on the comfort attribute, we could accurately predict the choice.

The random utility model (RUM) as presented by Walker and Ben-Akiva (2002) is derived from early psychologist work of Thurstone (1927) to describe preferences with a utility function concept. Applying this into economics was initiated by Marschak (1960). The functional form for economics is specified in Lancaster (1966) and seminal work in the field was done by McFadden (1974). We note that in RUM framework it is argued that the researcher cannot observe all the characteristics of the utility. The utility equation is represented by:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

In equation (1), we have decomposed the utility into two parts. The associated utility level U_{ij}, that the decision maker i gets from selection alternative j, is determined not only by the typical observable component V_{ij} but also by an unobservable component[2], ε_{ij}. The unobservable component is treated as a random variable. We will open up what assumptions of its density can mean for modelling purposes in section 4.2 on discrete choice models. (Train, 2009, pp. 14–19.)

The corresponding general choice probability statement that consumer i chooses alternative P_j in the RUM is:

$$P_{ij} = Prob\ (U_{ij} > U_{ik})$$

$$\Leftrightarrow P_{ij} = Prob\ (V_{ij} + \varepsilon_{ij} > V_{ik} + \varepsilon_{ik})$$

$$\Leftrightarrow P_{ij} = Prob\ (\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik}), (0 \leq P_{ij} \leq 1) \qquad (2)$$

In the simplified practical example, we assume that the utility from the two characteristics is directly additive with no interactions, it would follow that the probability P that PH is chosen is $P_{PH} = Prob\left(\varepsilon_{\mathrm{EH}} - \varepsilon_{PH} < (c_{PH}\gamma + m_{PH}\delta) - (c_{EH}\gamma + m_{EH}\delta)\right)$. Now assume that the numbers compute in such a manner that pellet heating is the predicted choice by one unit. What if the consumer chooses electric heating? This must have meant that our model omitted some unobserved factors ε_{ij}, that more than offset the difference between the observed components.

It would be possible to use another approach as well. Theoretical framework behind behavioural analysis including attitudes and preferences is often based on consumer behaviour, innovation or technology diffusion models. The diffusion of innovations theory first published in the 1960s is available in its fifth edition by the originator Rogers (2003). It can be used to study how new inventions enter the market. The theory can also be modified to mimic the trigger situation when a need for a new heating system arises. We mentioned Hecher et al. (2017) as an example of this.

Earlier we noted possible inconsistencies in a multinomial decision situation. With the rise of new behavioural economics and the incorporation of its ideas with standard microeconomic theory, the rationality assumption does get challenged much more.

[2] Term epsilon ε is standard practice for its representation in the literature. As pointed out by Henser et al. (2005), it can easily be but should not be confused with an error term. It is behaviourally determined.

The bounded rationality theory stemming from the work of Simon (1955) has been applied in choice situations. One could argue, that instead of capturing consumer heterogeneity, a discrete choice model variance reflects bounded rationality (Golman, 2012). It is possible to have models account for that as well. A mitigating factor in discrete-choice analysis is that we are comparing what factors explain the choice of competing systems instead of necessarily having to assume total utility maximization. Below we will discuss the regression models based on the RUM-approach unless stated otherwise.

4.2 Discrete choice models

Different choice models that are based on random utility framework stem from different treatment of V and ε in solving (2). We first introduce the most widely used approach known as logit. It is possible to derive logit models from the random utility model framework, an approach completed by McFadden (1974). First one has to restrict the density of ε_{ij} in equation (2) to $f(\varepsilon_{ij}) = e^{-\varepsilon_{ij}} e^{-e^{-\varepsilon_{ij}}}$, which is necessarily independent and identically distributed (iid), with independent Extreme Value Type I (Gumbel) distribution[3]. Then following McFadden (1974), cumulative density function becomes

$$F(\varepsilon_{ij}) = exp(-exp(-\varepsilon_{ij}). \tag{3}$$

Choosing this that leads to equation (3) cumulative density is functionally convenient in that the probability for individual choice can be solved in closed form (Train, 2009, p. 34). Logistic distribution has more observation in tails than a normal distribution. The logit choice probability with this assumption is:

$$P_{ij} = \frac{exp\, V_{ij}}{\sum_{k=1}^{j} exp\, V_{ik}} \tag{4}$$

[3] Following the original text, the distribution used here is often incorrectly classified to be Weibull.

Next, we assume that the observed utility in equation (4) being linear in parameters: $V_{ij} = \beta_j x_i$. We introduce to the notation the explanatory variables x_i and their estimated parameters for the alternatives β_j. It follows that generally or for an individual to choose option j over k options:

$$P_{ij} = \frac{exp(\beta_j x_i)}{\sum_{k=1}^{j} exp(\beta_k x_i)} \tag{5}$$

Equation (5) is the multinomial logit model, where the explanatory variables vector x_i consists of the characteristics of individual i such as income and location. Since the estimated parameters β are not the same for each decision maker, there is heterogeneity. In a closely related case, if we had the explanatory variables vector x_{ij} representing the variation of attributes of option, things like the look and investment cost of the heating system, we would have what is often referred as conditional logit model. (Greene, 2012, pp. 801–808.)

An important matter for analysis purposes is to look at marginal effects. In discrete choice modelling, their study must be done with great care. The marginal effects are computed with the following formula, attained by differentiating the model:

$$\frac{\partial P_{ij}}{\partial x_i} = P_{ij}[\beta_j - \sum_k P_{ik}\beta_k] = P_{ij}(\beta_j - \bar{\beta}). \tag{6}$$

The marginal effect depicted in equation (6) thus depends always on the parameter estimate β_j and choice probability P_{ij} and on the remaining effects, with every sub-vector, that is all the remaining coefficients of β being present in each marginal effect. A change in one individual characteristic, ceteris paribus, impacts on the choice in question and every other choice as well. (Greene, 2012, p. 804.)

4.3 IIA assumption

It follows from our RUM framework and multinomial logit model derivation that the independence of irrelevant alternatives (IIA) condition applies. Luce's (1959) choice axiom means that we expect there to be no cross-correlation among alternatives. Relative probability or the ratio of two options $Pi\,/\,Pj$ should stay the same irrespective of the characteristics of any third option. This is an implausible assumption if there are close substitutes introduced into the choice set. (Train, 2009, pp. 45–50.)

In economics literature following McFadden (1974), it is commonly known as the red-blue bus problem. In his example, there are two modes of travel available, a car or a (blue) bus. If two-thirds choose the car and one third the blue bus, since $\sum P_{ij} = 1$, $P_{car} \approx 0.67$ and $P_{bluebus} \approx 0.33$. Then the ratio $P_{car}/P_{bluebus}$ = 0.67/0.33 = 2. If we now introduce a third option, a second (red) bus, we might intuitively assume that all else equal, it would take market share from the blue bus. This would mean that the car/blue-bus ratio would grow. If the two busses share the 1/3 market share, their shares are 1/6 each, and it follows that $P_{car}/P_{bluebus} = 4$. To satisfy the IIA assumption, we would instead expect a 0.5-0.25-0.25 split or something else that changes the two-thirds market share of the car option yet maintains the original P_i/P_j ratio. Formally estimates from the full model (5) should be compared with

$$P_{ij} = \frac{exp(\beta_j x_i)}{\sum_{k=1}^{m-1} exp(\beta_k x_i)}. \tag{7}$$

In equation (7) option l is dropped from the analysis.

Generally, any IIA test will compare the β estimates. So-called Hausman test (Hausman & McFadden, 1984) is one of the main tools for testing IIA. Following the presentation from Cheng and Long (2007), the Hausman test statistic is:

$$H = (\hat{\beta}^r - \hat{\beta}^u)' \ \left[Var\big((\hat{\beta}^r\big) - Var\left(\hat{\beta}^u\right)\right]^{-1}(\hat{\beta}^r - \hat{\beta}^u) \tag{8}$$

Equation (8) includes unrestricted ($\hat{\beta}^u$) and restricted ($\hat{\beta}^r$) model βs for non-alternative specific variables and the variance-covariance matrices of the estimates. If it turns out that independence of irrelevant alternatives axiom is violated, solving this issue is possible with a more complex formulation such as nested logit or mixed logit.

5 DATA AND VARIABLE DESCRIPTIONS

5.1 Data description

In 2012, there were about 12 000 detached houses built in Finland and in 2013 around 9000. In 2014, the number of finished detached houses fell to 8375. The 8375 houses corresponded to 28.6% of all completed houses during 2014. By 2017, due to booming flat construction, the rate had gone down to 20.7% and the absolute number was 7387. Regardless, approximately half of the Finns live in detached houses. Their average size in 2017 was 111.8m^2 whereas the average size of a flat was 56.1m^2. Correspondingly the energy need of a detached house is also significantly larger. Furthermore, with detached houses more often being built under the guidance of the house owner, she can be assumed to be the decision maker. Despite recent urbanisation and increased block dwelling, almost 40% of the total building stock and most of the residential floor space is still in single-detached houses. (OSF, 2018.)

In this thesis, the focus is on newly built detached houses in Finland that were completed between January 2012 and May 2014. We will be examining data from the 432 households (out of a random sample of 2000 drawn through civil registry), who responded to a mailed questionnaire[4]. The questionnaire was addressed based on building registry. The data contains answers to socio-demographic characteristics such as age and income, home characteristics including building size and spatial characteristics such as location. We also have a detailed account on the primary and supplementary heating system choice of the household. (Ruokamo, 2016.) In table 3 we have listed some demographic and home-specific descriptive statistics of the respondents. The variables are explained more thoroughly in section 5.3. Missing answers are reflected when a variable does not summarize to 100%.

[4] The data gathering was supported by the Academy of Finland Strategic Research Council project BC-DC (AKA292854).

Table 3. Survey respondents' descriptive statistics.

Owner stats (n=432)		House& area stats	
Owner age mean	42,6	House size:	
Household size mean	3.26	<100 m^2	5.6%
Have kids at home	60%	100-149 m^2	39.3%
Gender:		150-199 m^2	39.3%
Female	25.7%	200-249 m^2	8.8%
Male	73.8%	>250 m^2	6.5%
Income:		House type:	
<2000	3%	Normal	43.5%
2000-3999	14.4%	Low-energy	43.1%
4000–5999	33.3%	Passive-energy	5.3%
6000–7999	29.2%	Zero-energy	0.2%
8000–9999	10%	District-Heating:	
10000–11999	4.2%	Network near	21%
12000–13999	0.9%	Not near	75.4%
>14000	3%	Settlement:	
Forest owner:		Rural	30%
Yes	28.7%	Village	5.1%
No	70.8%	Township	23.1%
Education:		Small city	14.4%
Basic	7.6%	City >50000	25%
Secondary	36.8%	2nd heating system:	
Polytechnic	33.1%	Yes	91.8%
University	21.5%	No	7.2%

Figure 2 shows shares of the primary heating systems in our data. Close to half of the respondents chose ground source heat pump. Ground source heat pump is one separate dependent variable in our analysis, and it is named *GrndHeat*[5]. It was followed in order of frequency by direct electric heating and exhaust air heat pump, both with over 10% share. District-heating, electric storage heating, solid wood heating and air-to-water heat pump followed with shares of 5–10%. Only few households chose wood pellet heating, oil heating or any other methods.

[5] Across this, thesis we italicise the name of the variable we use in our analysis.

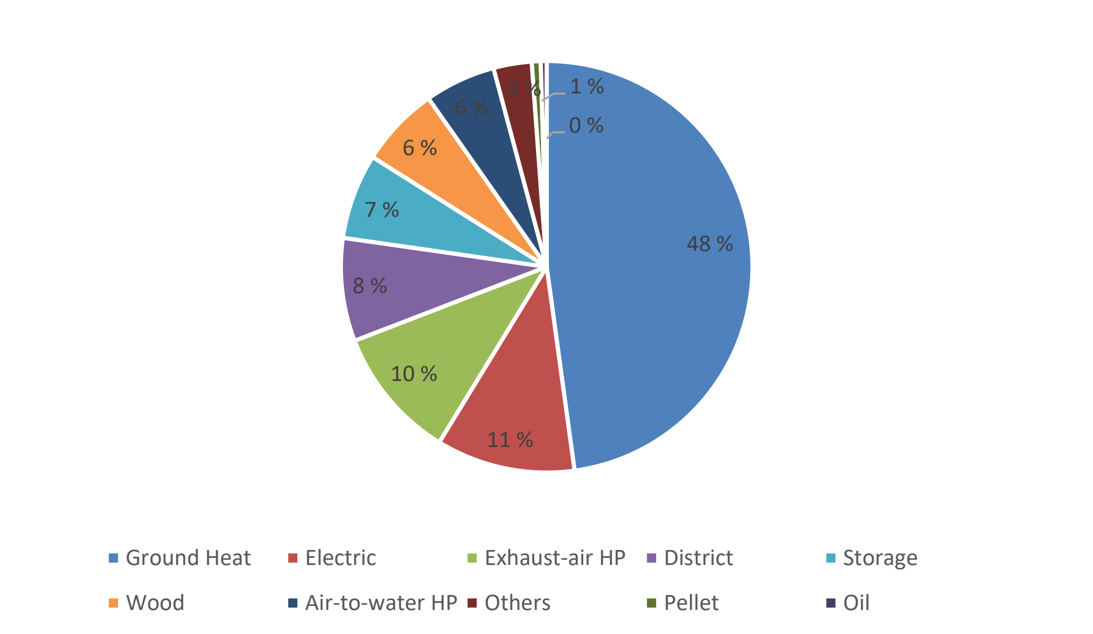

Figure 2. Heating system shares in the data.

It is typical for Finnish houses to have more than one heating system (Ruokamo, 2016). Table 3 shows, that 397 houses (over 90%) have some system that could be used as a secondary heating system in this sample. Most often, the secondary heating system is a fireplace, which not only acts as a backup-system but is seen as a decorative element and oftentimes can be used for reasons other than heat generation. There are 445 wood-based supplementary heating systems *WoodSHS* divided between 383 households and 70 non-wood heating systems in total divided amongst 67 different households. The data includes solar heat collectors (20) and solar panels (4), air source heat pumps (44) and storing chimneys (2). We deem the non-wood-based systems, coupled with the 14 observations of a water-circulating fireplace, a total of 84 systems, to belong in what we coin innovative supplementary heating system *InnosShs* (n=75).

There are no major issues regarding the representativeness of the data. Compared with the 2012–2014 share on figure 1, we have a strikingly similar heating system selection profile. Excluding exhaust-air heat pump, the share of which is 3.6 percentage points higher in our respondents' group, all the observations fall under two percentage point's variation in between these surveys. Figure 1 includes 6% share for hybrid heating solutions. It is probable that the higher share of both exhaust-air and air-to-water heat pump, as well as the section others, jointly capture the hybrid heating share in our survey. Both surveys are slightly over-representing southern Finland. For us, this is due to Oulu-region data being collected separately. Our survey covers entire 2012-2013 and cuts-off in May 2014. There were large variations in figure 1 from 2013-2014 particularly with direct electric heating (10% vs 17%), other wood (10% vs 3%) and exhaust-air heat pump (7.5% vs 4.5%). There was no corresponding sample-level information on income, education, forest ownership or living environment to check for representativeness.

To further stress the importance of our data, we compare vis-à-vis recently conducted survey by Official Statistics of Finland and National Resource Institute LUKE on small-scale use of wood in small residential buildings. The study is widened to cover all the heating energy choices of such houses. The preliminary news item drafted based on those findings highlights that primary heating system data in the national building registry is not accurate. There exist unusually large differences between the registry and the snippet info. The portion of ground heat is twice greater (10 % vs 5%) and oil heating smaller by a third (24% vs 16%) among the roughly 4100 respondents than in the registry data. This is a highly statistically significant difference. There are at least two potential sources for the inaccuracy. Firstly, the renovations are not added into the registry. Secondly, if the decision to change the primary heating system has been made after applying for the permit, the registry will also have the wrong information. The building registry also does not classify between different types of wood burning stoves. (Tieto & Trendit, 2018.)

Our data also has certain advantages compared to multi-criteria decision analysis conducted before the final building decision or choice experiments and other hypothetical scenarios alone. We are using data that reveals both the real choices that have been made by the owners and stated preferences. Often researchers can get revealed preference data only on the chosen alternative. Here we have more. Additionally, since we are talking about real scenarios, we do not need to limit ourselves to some standard-house, but we get to observe the effects of real variables through marginal effects. (Hensher et al., 2005, pp. 88–98.)

One advantage of individual microdata absent confounding compared to pooled census data is that it does not suffer from aggregation problem (Deaton & Muellbauer, 1980 pp.148–149). Ben-Akiva and Lerman (1987 p. 1) use the term disaggregate travel demand models when discrete choice analysis methods using individual level data are used. They note, that there will be loss of precision if the variables are not homogenous across groups. For inference's sake, we still want to explore aggregate data. When individual-level microdata is available, we can account for the bias so that there is no contradiction between the aggregated results and micro-level predictions. The two issues above suggest that having individual level results allows accounting for heterogeneity and the use of more explanatory variables.

5.2 Dependent variable descriptions and modelling approach

Dependent variables in our analysis are the primary heating systems, which are unordered and categorical. The explanatory variables used will be described in the following section. In the bivariate analysis, we investigate a single heating system and see which effects appear to have an impact on its selection. Bivariate analysis is later used to determine the attributes that we carry forward to multivariate analysis. (Hensher et al., 2005, pp. 218–246).

We have explained in section 4.2 that for logit analysis, we link the choice with the Gumbel distribution. Doing this the explanatory variables summation takes a value in between 0 to 1. The predicted outcome of the binary choice is 1 or yes when probability is above 0.5. In the bivariate analysis of *GrndHeat* we run a full-dummy model. In our chosen approach, the probability that the household chooses ground source heat pump is some function of the estimated components and the unobserved factors. Let us first highlight the binary choice *GrndHeat* = [0,1], which is that the individual either chooses a ground source heat pump or any other system. Probability P_{GrndHeat} is a function of the individual characteristics, and the individual choice is defined as either choosing to acquire ground heat system or any other system. Assuming that ε_{i} is logistically distributed, the maximum likelihood estimation resulting coefficient model with the variables that conform to our hypothesis on this choice is estimated to fit a log-odds function

$$log\ \left(\frac{p}{1-p}\right)_{GrndHeat} = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n. \tag{9}$$

In choosing between a linear and multiplicative formulation for parameters in equation (9), the linear form is computationally simpler. It is normally a reasonable approximation. If we have a model that is linear in parameters:

$$P(GrndHeat) = \frac{1}{(1 + exp\,(-(\beta_0 + \beta_1 X_I + \ldots + \beta_n X_n))}. \tag{10}$$

When we input individual numbers as to which group any decision maker belongs to the equation (10) containing the estimation βs, we predict a choice of ground heat system when the probability of it is greater than 0.5. The multinomial logit estimates are simply an extension of the equation (5). (Train, 2009, pp. 37–40.)

The benefits of hybrid heating are considerable (Ruokamo, 2016). Therefore, it is very relevant to inspect the supplementary heating system choice, which is an understudied area. We will run a binomial logit analysis, adding at least one innovative supplementary heating system *InnosSHS*. These systems are meant to provide supplementary heating. The other wood-based systems—baking oven, fireplace and air-circulating fireplace have auxiliary uses. We specifically asked do you use any other supplementary heating system, which excludes outside-air heat pumps solely used for cooling.

Finally, we move into the multinomial analysis of the primary heating system choice. A multinomial logit model has each dependent variable dummied. Since utility level and scale do not matter, mathematically one alternative needs to be normalized to form the reference alternative. We have already mentioned this for categorical attributes. For choices, this is done by setting one of the choices' β to zero. The interpretation will be compared in relation to this reference group. When we run the entire model at once, results should mimic binary regression results, since each dependent variable is run through a binary model comparing its probability to the reference category. Simultaneous estimation should reduce unexplained portion. (Hensher et al., 2005, pp. 308–373.)

McFadden (1974) points out that in order to use multinomial logit model, we should have a situation with distinct and independently weighed alternatives. Towards that end, we have pooled choices that we view as potentially close substitutes. In this manner, we have a robust number of observations in each category. Long and Reese (2006) also argue that model quality is improved when indistinguishable groups are combined.

We will treat the largest *GrndHeat* separately. The air-to-water and exhaust-air heat pump are combined as *HeatPump*. With the differences in daytime and night-time electricity prices showing a downward trend (Sahari, 2017), storage heating and direct electric heating are even closer to one another as options and are treated together as *Electric*. The two wood-based technologies, pellet heating and wood heating are combined into *Wood.* Finally, district heating and the group others that includes area heating and other larger-scale systems as well as couple oil observations are combined under *DHetc*. Doing this we have a minimum of 30 observations in each group, each representing a minimum of 7% of total responses. This total combination is shown in Figure 3. The ratio of required cases to explanatory variables in multinomial logit is a contested matter. In our study, the amount of *Wood* observations and thus the results pertaining to it is the most critical in this regard. (Jong et al., 2019)

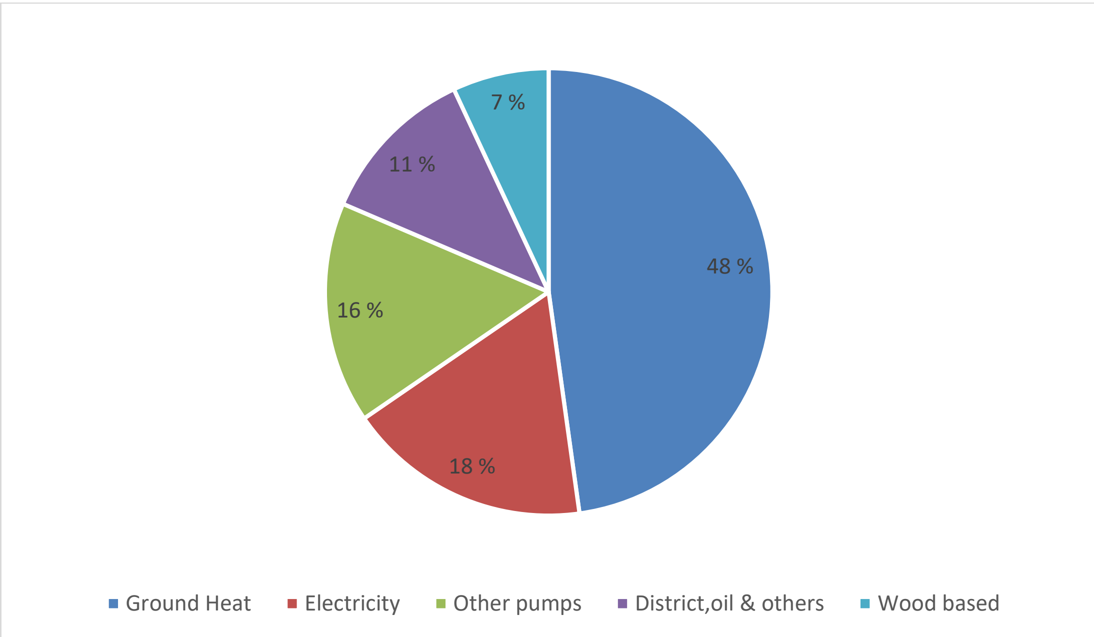

Figure 3. Combined heating system shares for multinomial analysis.

5.3 Explanatory variables

In the following, we describe the explanatory variables we have at our disposal. We categorise them following Michelsen and Madlener (2012). When we include categorical independent variables, one category in each will be the reference group. With non-linear attributes or ranges that have no apparent reason to consider all of them separately, we do create new variables in the code to account for this. The most common approaches to code such interval-level data into econometric software analysis is to use dummy-coding or to effects-code them. (Hensher, et al., 2005 pp. 144–147). The debate on which to use is not conclusive (Daly, Dekker & Hess, 2016). We will be applying the dummy-coding approach. When there are missing observations in the data pertaining to the variables entering our model, instead of imputing a value to the observation, which would potentially bias the results, we have chosen to exclude those observations.

5.3.1 Socio-demographic

The summary statistics of responses for socio-demographic variables are listed in Table 4. We have ordinal numeric 8-range equal-length intervals *Income* data. Income may affect the financial possibilities of a household (Michelsen & Madlener, 2012). Ability to attain financing for a more expensive system may be impacted. Interpretation wise, a jump from one range to another of this continuous variable represents a shift from mid-to-mid of the range. Observations in the tails are a little more problematic. Of course, we can also dummy-code *Income* assuming a high income above a certain level. We have done this for over 6000-euro monthly income that we label *HighInc*.

The family size *FamMbrs* may also be a determinant. As Braun (2010) points out, a larger number could mean a higher comfort level requirement. The fewer hours spent home by smaller families who then would require less heating does not seem quite as applicable in Finnish conditions. Leaving a room without heating seems atypical. If there are under 18-year-old family members, we list that the household has *kids*. A family of 5 or more is considered with *BigFam*.

Table 4. Socio-demographic variables.

Variables	Explanation	Yes/Type
Income	8-ranges, continuous euro-dominated	8 categories
HighInc	Household *Income* above 6000€/month	48%
Age	Age of the individual (42.6, 12.6, 23–73)	Metric
Young	*Age* <40	56%
MidAge	*Age* 40–60	31%
Senior	*Age* >60	13%
Female	Respondent identifies as female	26%
FamMbrs	Number of inhabitants (3.26, 1.37, 1–10)	Metric
Kids	If the household has under 18-yo inhabitants	60%
BigFam	More than 5 *FamMbrs*	14%
HighEdu	Polytechnic or university-educated	55%
Profield	Technical or construction industry professional	47%
Constru	Construction industry professional	19%
Worker	Lower-level & other employees	33%
OwnWood	Can get firewood from family sources	29%

In brackets: Mean, standard deviation, range

We have the information concerning the birth-year of the respondent. From this, we calculate *Age* at the time of answering the questionnaire. Since the responses were sought from people who had built their house within the previous two-year period, an individual will be 0–2 years older than at the time of completing the house. Dummy-coded groupings that we test are *Senior (>60), MidAge (40–60)* and *Young (<40).* The older the person, the more experience has been gathered on average. Conversely, an older individual may insist on a shorter payback time on investment or have a different risk-profile (Michelsen & Madlener, 2012)

We mailed the questionnaire to whom we considered the principal owner. The gender of the person who responded to the questionnaire is treated through a variable listing whether the individual identifies as *Male* or *Female.* Much of the heating system literature including Michelsen and Madlener (2012) uses gender as one choice determinant. They find minor positive impact for a more traditional system gas and argue that females might be less technically versed and more risk-averse toward innovative systems. We find this argument a little bit tenuous and find no clear-cut guideline here on what to expect from published gender effects studies. Furthermore, when you do not live alone, most often the case in detached houses, it is reasonable to expect the heating system decision is not made solely based on your preferences and technical expertise. We could not even be confident whether the principal owner was the one answering the question. We do deem this kind of reasoning worthy of testing when it comes to innovative supplementary heating system *InnoSHS*.

We asked for information regarding the highest degree completed. We categorize the degrees after second-grade education to represent a highly educated decision maker *HighEdu*. Braun (2010) reasons that higher education can be associated with heightened environmental awareness, higher opportunity cost of time and better perception of the real costs of the system. The different valuation placed on the cost of time is also analogous with the thinking in household production theory, where household activities performed on the acquired good add value to it. Following Becker (1965) this line of thinking has households combining market goods and their time into a new and improved good. It could be modelled by adding available time into the budget constraint in the maximization problem. The opportunity cost for an extra hour needed for heating system operation may differ across individuals, in turn making household production more expensive for higher earners, so this could be associated with the income as well. Sahari (2017) also finds that higher education implies investing more upfront. She attributes the better understanding of the true costs to be related to variable costs. This would suggest a lack of understanding could partially explain energy paradox. Assuming these preferences and characteristics alone would suggest higher education leading into choosing more environmentally friendly, less maintenance and preparation work demanding and lower variable cost system, ceteris paribus.

We examine if the occupation of the respondent is in some way connected with the heating system choices. The possibilities include agriculture, construction, technical or the environment. We position that technical or construction professionals may be more willing to select a more operationally difficult, more maintenance requiring system and treat them as a single group *ProField*. We also check the same for construction professionals *Constru* alone.

Our field of work data is classified in 9 categories. We hypothesize that people working for others (*Worker)* are a distinct group. This variable includes lower-level employees with administrative and clerical occupations and other employees. The assumed difference here is that they have less flexible working hours. They also have a more secure and less volatile earnings profile. We also have data on the ability to attain firewood from own sources through family forest ownership answer *Ownwood*.

5.3.2 House-related

Since all the surveyed houses are freshly built, they are more uniform than if we were studying existing houses. The house-specific variables of our data are listed in table 5. Where the other attributes are concerned, we hypothesize that the size of the house *Homesize* is expected to influence heating system selection. The variable is 5-category listing of a continuous variable measured in square meters. We also separately test *BigHome* for houses over 150m^2. The systems with higher investment cost and lower variable cost become relatively cheaper to use, the bigger the house is, and conversely the smaller the house, the less heating energy is needed, which should favour cheaper to buy but more expensive to use alternatives.

Michelsen and Madlener (2013) introduce a low-energy house variable for newly built homes. They find it to have statistical significance. We are mindful that these decisions are made in consort. Does household tailor energy grade planning with the heating system or does it just reflect other underlying preferences? An interaction effect with house size may also exist. By our analysis, the most prudent way seems to be to separate the houses with -30% or more stringent energy level than that of the minimum standards for a variable called *LowEnerg*.

District heating is a viable solution only if the house is located next to an existing district heating network infrastructure *DHNe*t. There are 13 households who are unaware if the district heating network is close to their house. We assume that for these households, district heating network is not in the vicinity. Separately the primary heating systems and *SuppHS*, as well as the variable derived from them, may enter regressions of the other systems as explanatory variables.

Table 5. House-specific variables.

Variables	Explanation	Yes/Type
Homesize	Heated floor space in square meters	Metric, 5-cat
Bighome	*Homesize* over 150m^2 heated floor space	55%
Energy-level	Normal, low, passive or zero-energy house	4 categories
LowEnerg	Low-energy (-30%) or more stringent *Energy-level*	49%
DHNet	House in district heating network area	21%

5.3.3 Geographical area

The geographical location is expected to play a role as well. The variables on that basis are listed in table 6. We have location data on postal number level. Based on this, we identify three possible geographical explanatory approaches. The first is through so-called heating degree days. The amount of heating needed rises relatively linearly as we go northward. The Finnish Meteorological Institute FMI (2019) publishes detailed heating degrees days data on its website. In their definition, a heating degree day is measured as by the difference of daily indoor and outdoor temperature. The basis for the calculations here is a measure called S17. The indoor target temperature is 17°C. The remaining heating need is expected to be filled by the inhabitants and excess equipment heat. It is assumed that heating degree need is the difference between 17°C and the daily average temperature. When the average temperature rises above 10°C in the spring, the heating is presumably turned off. In the autumn heating is started when the temperature falls below +12 degrees Celsius. The FMI reports both an annual and a monthly measure. We have labelled the areas *HeatDgr* based on annual reading for this measure from 1–4 in Figure 4. FMI has municipality level multipliers available for calculation of the heating degree days for the said area.

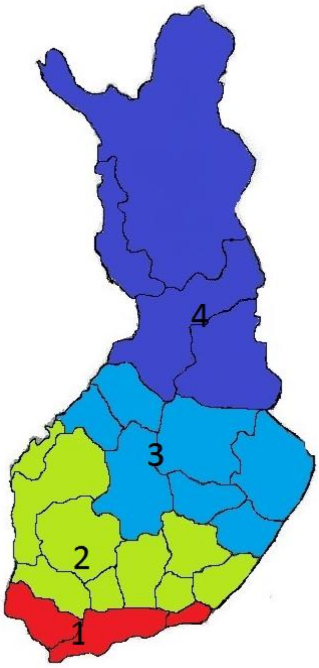

Figure 4. Heating degree range map (Adapted based on Posti (2019) and FMI (2019)).

Previous use of heating degree days based variable includes Lillemo et al. (2013). The annual heating degree days measured as normal based on 1981–2010 interval for the areas 1–4 as shown in figure 4 fall roughly like this:

1: 3800–4000

2: 4000–4500

3: 4500–5100

4: 5100–6300

It is also possible to treat regions separately; for instance, area 4 can be classified as *North*. As discussed in section 3.2, all the systems are mostly capable of providing sufficient heating across the country. Still, the costs of doing it do differ. When more heating days are required, operating costs differences become a relatively larger factor. This can affect heating mode choice.

Detached houses use of firewood is studied by Luke (2018b). Lowest average use of firewood per those who used firewood was in area 1 of Figure 4. It could relate to the higher social costs, less cold days that require supplementary heating and a smaller percentage of wood-based primary heating systems.

The second approach is what we will call as coastal-non-coastal divide and measure it with variable *NoCoast*. The eastern and northern parts of Finland lie away from the Baltic Sea. The sea is enveloping the southern and western parts of Finland. Sea in itself can be an explanation. Being further away from the waterway may mean slower diffusion of new technologies though such an impact appears diminishing recently. Coastal regions generally have less variance in their temperatures as do inland areas. The open sea means autumns stay milder a bit longer and in spring the cold lingers. We will observe that the very fact that water absorbs and stores heat well, is why it is used in heat delivery. Relatedly, the slight tilt in *HeatDgr* should be due to this. If the *NoCoas*t takes a value of 1, the respondent house is in the green area of Figure 5.

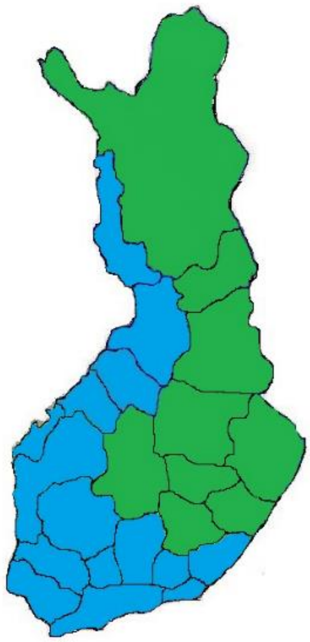

Figure 5. Coastal-non-coastal divide (Adapted based on Posti, 2019).

The East-West divide is prominent not only in the coastal divide. The reliability of the electric network is generally higher in the more densely populated southern and western areas where much of the network has been dug underground. In eastern Finland, much of the network is still above ground and suspect for power outages due to trees falling on the grid and in the winter from the snow pushing branches onto powerlines. The grid investment need in these areas is also larger, posing a bigger risk for future transmission price increases. The overall income level divide and wage level divide mean that construction and system installation costs are lower. (Sahari, 2017.)

In the third approach, we combined the three most distant areas represented with postal codes 70000–84000, 87000–9000 and >96000. We deem these areas as *remote.* When we consider technology-diffusion models, the most remote areas are expected to receive the newer and more innovative systems last. Being further away from urban centres may also make it prudent to focus on the security of supply with backup systems. We must be mindful that forest ownership numbers may differ across regions, from east to west and to some extent from north to south. This and the costs differences could suggest some interaction effects.

Table 6. Geographical area variables.

Variables	Explanation	Yes/Type
Settlement	Living area, from rural to big city	5 categories
City	*Settlement* in a City (township,big and small city)	62%
NoCoast	Out of coast location, green area in Figure 5	27%
HeatDgr	Heating degree days, increasing from 1–4	4 categories
1	Area 1 in Figure 4	29%
2	Area 2 in Figure 4	37%
3	Area 3 in Figure 4	24%
4	Area 4 in Figure 4	10%

The rural-urban divide is another matter that can impact the choice in various ways. We place people living in a township, municipal centre area or a bigger city together labelling the variable as *city*. The square meter cost of the plot and the construction costs for an extra room tend to be lower in the countryside. Wood-based heating systems take up more space; for example, pellet heating requires a storage room. Small particle emissions created by burning wood are assumed to be a smaller problem in the countryside. Fewer neighbours need to endure them. Social acceptance of residential wood burning may be much lower in cities. Furthermore, in Asplund (1984) rural customers seem to have larger long-run electric heating income responsiveness. District heating network availability is restricted to urban areas. The reliability of the electric network varies here as well; on average households in city plan area were without electricity for just over half an hour in 2016. Outside of the city plan area, it was almost 8 hours. With less destructive storms, the latter number halved to just around 4 hours for 2017. (Energiateollisuus, 2018b.)

5.3.4 Attitudes and other system-specific

We have details on the different sources that the respondents have used to get information on the heating systems. Information sources may play a role in the heating system choice. These represent the impact of information diffusion. Their relative impact is beyond the scope of this study. It is possible that during a said period some systems are promoted more frequently in some channel.

It is quite notable how much detached-house builders have attended exhibitions. We receive comments that some people will solicit offers from multiple contractors in exhibitions. Very few people state having gotten information on different heating systems from building control officials that we name *Supervis*. Specialists of the field, *Experts,* are a resource that many people do use. The most common sources of information were friends and acquaintances (*Friends*) and the *Interne*t. Also, Newspapers (*Newspap*), television (*TV*) and professional literature (*Literat*) are a common source of heating system information.

Correspondingly, there are rating-scale answers on stated contribution on heating system mode choice from specialists. Here we deem an answer of somewhat or strongly agreeing to the claim that specialists or experts have a great impact on heating system choice to lead to placement in the appropriate category. These variables are named in *PosExp* for expert opinions and *PosFrien* for other people’s opinions. Approximately half of the respondents said their acquaintances had an impact while expert opinions were said to have an impact by over 60%. It will be interesting to mirror these with the information sources and information impact. This information can prove useful for both system provider perspective and policy purposes. We list information sources and their stated contribution variables in table 7.

Table 7. RHS-specific information channels.

Variables	Explanation	Yes/Type
Supervis	Building supervision	10%
Experts	Professionals	53%
Friends	Friends and acquaintances	77%
Internet	World Wide Web	78%
Newspap	Newspapers and magazines	58%
Literat	Professional literature	39%
TV	Television	36%
Exhibit	Housing exhibitions	55%
FriendsM	Other people's opinions have an impact	Rating-scale 0–5
PosFrien	Fully or somewhat agree with *FriendsM*	49%
ExpertM	Expert opinions impact my RHS choice	Rating-scale 0–5
PosExp	Fully or somewhat agree with *ExpertM*	62%

Another line of residential-heating system specific information we have is stated preference rating-scale[6] data from the respondents on how important they view Investment costs *InvCostM*, variable costs *VarCostM*, the comfort of use of the system *ComfortM* and environmental friendliness *EnvironM*. A significant amount of people chose the highest importance option. These answers are used as separate dummies called *InvCIMP, VarCIMP, ComfIMP and EnvirIMP*. The cost and environment -related variables are summarized in table 8.

[6] One widely known example of a rating-scale is a survey technique where responses indicate the level of agreement or disagreement in similar intensity called Likert-scale after *Likert, R. (1932)*. In this case we ask the level of importance that the respondent places on the action in a type of 1-5 rating scale application where we also included a do-not-know option.

Table 8. Costs and environment related variables.

Variables	Explanation	Yes/Type
InvCostM	How important are the investment costs	Rating-scale 0–4
InvCIMP	*InvCostM* very important	44%
VarCostM	How important are the variable costs	Rating-scale 0–4
VarCIMP	*VarCostM* very important	80%
EnvironM	The importance of environmental friendliness	Rating-scale 0–4
EnvirIMP	*EnvironM* very important	29%
ReneblUp	Increasing share of renewables importance	Rating-scale 0–5
EnerSave	Energy saving importance for climate change	Rating-scale 0–5
NMental	*EnvironIMP=yes*&*ReneblUp*>4&*EnerSave*>4	13%
EcovTrad	Willing to pay more for ecological RSH	Rating-scale 0–5
PayEco	Strongly or somewhat agree with EcovTrad	39%
DHisEco	District heating is ecological alternative	Rating-scale 0–5
SolarLow	Solar energy use is too low in heating	Rating-scale 0–5
NoOilEle	RSH must be more ecological than oil / electric	Rating-scale 0–5

Sizeable portion of the respondents did not view either of the cost components as an important determinant for heating system choice. Social safety networks that provide housing benefits in case you are unable to cover the costs yourself may make one care less about variable costs. It is also conceivable that some people have a very short planning horizon or the financial means not to care. Investment cost into a more expensive system might be viewed as a store of value as well. Concerning education, we mentioned that some individuals might not have similar foresight into the real impact of lifetime costs. If there are capital market inefficiencies, the investment cost may become a relatively more pressing matter. A person may have different expectations of his/her future earnings potential than the credit markets do. Their discount rates may also vary. There may also be greater uncertainty regarding variable costs of different systems.

We highlighted in section 3.3 how investment and variable costs could also differ based on house characteristics and location. There will be regional variation. The general assumption in economics is that we have perfect price visibility, functioning capital markets and complete information. In that case, the decision makers should be able to determine the cheapest lifetime cost of a system and choosing a more expensive system would be due to other factors.

We also possess the environmental attitudes of the respondents, who were asked how important it is to save energy to mitigate climate change *EnerSave*. The respondents asked how important it is to increase the share of renewables in the energy mix, even if it means additional costs to society *ReneblUp*. While most of the people considered themselves interested in environmental issues, it does not mean putting money where your mouth is. Only around 10% were heartily willing to pay more for an ecological heating system and under 40% somewhat willing. Environmental values are also an issue that people more likely over- rather than underrepresent in their answers. While anecdotally it would seem that the current discourse may be changing this, free-riding is still a major issue. We combine the highest-level answers in *EnerSave*, *ReneblUp* and *EnvironM* to a single category *NMental*, which we suggest would represent environmentalist values.

The real environmental impact of different heating systems is not entirely straightforward. One of the more contentious issues was the environmental impact of district heating. Objectively people may be able to answer this based on their local operators' environmental footprint. No such controversy existed with solar thermal heating. The overwhelming majority feel that the use of solar heating in household space heating is too low. In total, 87% somewhat or strongly agreed with this statement. Using the same categorization, district heating is an eco-friendly alternative according to 42% of the respondents. The residential-heating system needing to be more ecological than oil or direct electric heating got affirmation from 76%.

The remaining heating-system specific variables are listed in table 9. Stating impact from energy performance certificate considered to belong to *PosElabl*. The label might impact secondary heating system choice as well, where especially *electric* energy grade can be improved. Testing this we get feedback on the effectiveness of this policy tool. The grade needs to be announced to the buyer if the home is being sold.

Table 9. Other RHS-specific variables.

Variables	Explanation	Yes/Type
ComfortM	The importance of system comfort	Rating-scale 0–4
ComfIMP	*ComfortM* very important	68%
WoodWork	Solid wood heating offers nice daily activity	Rating-scale 0–5
PosWood	Fully or somewhat agree with *WoodWork*	64%
SpaceM	Space needs strongly impact my RHS choice	Rating-scale 0–5
SpaceIMP	Fully or somewhat agree with *SpaceM*	25%
WoodTime	Daily rhythm too busy for *wood*	Rating-scae 0–5
Busy	Somewhat or fully agree with WoodTime	47%
Verybusy	Fully agree with WoodTime	27%
LowerTMP	I am willing to lower ambient temperature	Rating-scale 0–5
ColdOk	Somewhat or fully agree with LowerTMP	66%
ElablM	Energy performance certificate impact	Rating-scale 0–5
PoseLabl	Fully or somewhat agree with ElablM	35%
SelfSusM	Heating system should be self-sufficient	Rating-scale 0–5
SelfSust	Somewhat or fully agree with SelfSusM	73%
Autarky	Fully agree with B8m	28%
ElPriexp	Electricity price will rise markedly in the future	Rating-scale 0–5
ElpricUp	Fully or somewhat agree with *ElPriexp*	79%
ElpricXP	Fully agree with *ElPriexp*	37%

With *ColdOK* we asked if respondent would be willing to lower ambient temperature to save electricity. We position that answers to this question may capture two distinct effects. First, it speaks to being able to adjust the system temperature more flexibly.

Second, it can also show willingness to withstand a system that does not provide constant temperature but is for instance somewhat colder in icy outside conditions or during a fast drop in temperature. Also, a family with large internal differences in ambient temperature level preferences might prefer such adjustments.

There is also information on the attributes of the heating systems and how important the respondents thought those attributes were for their heating system choice. Specifically, we ask on if they view making firewood for solid wood heating is a nice daily activity and those who agree are labelled *PosWood*. Similarly, we ask if the respondents view that there is enough time to do such activities. People who weakly or strongly agree with this place in *Busy* and *Verybusy.* Hectic daily rhythm suggests that simple automated control systems should be available in the market. The importance of space requirements for heating systems is studied with *SpaceIMP*. It is another matter that is likely connected with *Wood* selection,

Additionally, there is information on the heating-system related training that the respondents received. Furthermore, there are interesting perceptions answers when the respondents were asked to comment on claims of attributes of specific heating systems. Other fascinating aspects include perceptions on the reliability of use of different systems. We will briefly report on survey comments and post-decision happiness after the multinomial logit results in section 6.3.

Alternative-specific classification of explanatory factors in this manner is further justified by the fact that it would be difficult to come up with objective ways to measure heating systems comparison accurately. For instance, comparing emissions from the use of wood heating to electric heating will depend on the type of wood used and the way that electricity is generated. On the other hand, coming up with a rank order is sometimes possible. One such example could be the number of hours needed for system maintenance. (Kasanen, 1990 p. 22.)

6 RESULTS AND IMPLICATIONS

6.1 Ground source heat pump selection determinants

We start by examining the determinants of the ground source heat pump choice. A convenient property in our dataset is that the predicted probability for ground heat is very close to 50%. Coupled with the fact that we have chosen only dummy-coded explanatory variables for this model makes the interpretation quite straightforward.

In Karytsas and Theoderopoulou (2014), internet and conversation with peers are the two most frequent information diffusion channels in learning about ground source heat pump with 55% and 45% respectively. Their intention to adopt ground source heat pump study indicates that financial constraints are the primary deterrent for its broader adoption in Greece. The variables that have an impact for intention to adopt include gender, education, income and occupation in environmental, technical or engineering field.

The marginal effects of our model estimation that enable inferences are shown below in Table 10. When we depict these results, we should remember that these are relative changes in probability compared to the actual one. If we say someone becomes relatively 10% more likely to select the ground source heat pump, we must compare that number to the predicted probability. However, as we stated, the predicted value for *GrndHeat* is close to 50%. The very illustrative property of the model here is that we are talking strictly discrete changes from one category versus another instead of marginal changes. We must keep in mind that even in case of dummy-coded variables, effects for those individuals who felt close to the edges can be less than towards tails.

Model goodness of fit statistics are shown at the bottom of Table 10. The McFadden pseudo R^2 reported here is calculated as $1 - LL/RLL$. In the two binary choice models of our study, the log-likelihood is compared to the restricted log-likelihood model that contains only a constant. In the *GrndHeat* model, McFadden pseudo R^2 is $1 - (-189/-283) \approx 0.332$. The inclusion of the correct predictions of the model is a matter of academic debate. Train (2012, p. 69) argues it should be avoided since the researcher does not have the information to predict the decision maker's choice. Greene (2012) notes that especially for unbalanced samples we should divulge correct predictions for both outcomes. We feel that the correct predictions statistics inclusion adds descriptive value to our binary choice models, but caution about too literal interpretation. The percentage of correctly predicted choices for *GrndHeat* is between 68–69% for both actual 1s and 0s. (Greene, 2012 pp. 741–745.)

Table 10. Binary logit model for ground heat choice.

Variable	Marginal effect	Standard error
Bighome	0.22611***	0.04514
Highinc	0.13113***	0.04518
Highedu	-0.01593	0.04201
City	-0.02429	0.04504
Young	0.04475	0.04017
DHnet	-0.15050***	0.05007
InvcIMP	-0.2558***	0.04087
VarcIMP	0.19893***	0.05179
ComfIMP	0.26430***	0.04539
EnvirIMP	0.05811	0.04446
Selfsust	0.10840**	0.04673
PosWood	-0.03792	0.04187
NoCoast	0.05521	0.04565
Posexp	0.15290***	0.04155
Profield	-0.03049	0.03957
Ownwood	-0.06423	0.04553
Model fit		
Observations (n)		409
Parameters (k)		17
McFadden pseudo r^2		0.33
Correct predictions at 0.5		69.2%
Log-likelihood		-189
Restricted log-likelihood		-283

***, **, * = statistical significance at 1%, 5% and 10% level respectively.

Our results show that having warm floor space in excess of 150 square metres makes the household almost 23% more likely to select ground heating. This is an expected and statistically significant result, with variable costs becoming relatively more important as heating space grows. Household gross income above 6000 euros per month increases the likelihood of ground heat selection choice by 13%. The *HighInc* is also statistically significant on the 1% level. These can be tied together, but it becomes evident that some financial constraints may exist. To stress this point, declaring that investments costs are an important determinant of heating system choice, as 43.5% do, makes the household over 25% less likely to get ground source heat pump. The investment cost impact suggests that we have households who would have preferred this alternative if they had the financial means. The respondents who consider variable cost meaningful for heating system choice are more than 20% more likely to decide to invest in *GrndHeat*. Living within a district heating network area brings down the ground source heat pump investment likelihood by 15%.

Ground source heat pump is seen as a comfortable system to run. When appropriately installed, its function is relatively straightforward. With some additional investment, it can also be used for cooling purposes during the summer. Those who view comfortableness of operation of the heating system important are 26% more likely to choose *GrndHeat*. It is also clear that the heating system experts in the ground source heat sector are pulling their weight. Declaring that expert opinions had an impact on system selection *PosExp* markedly raised the portion of adopters.

Many people who invest in *GrndHeat* feel that the heating system should be as self-sufficient as possible. While this is not entirely accurate, in the sense that you remain reliant on the electric network, the ambient energy that you do collect is literally from your plot of land. As it will turn out, respondents seem to view ground heat as the system that best meets the self-sufficiency desire, and the statistically significant impact in this binomial formulation for *SelfSust* is over 10%.

Finally, in a post-decision-making analysis out of the people who chose *GrndHeat* 35 people or 17% replied their heating system could use some improvements. Upon closer inspection, five of them were not related to the system itself but a myriad of issues such as the desire to invest in ground cool. The main issues for improvement were the difficulty of adjustments and relatedly uneven distribution of heat. These were together named 12 times.

Furthermore, two people noted that if they use firewood, ground heat system turns itself off too easily. A handful of people also complained of the noisiness of the system.

Our recommendation here is to develop systems that address these issues. Making sure that the settings are correct has an impact on pump performance. Therefore, it is an issue that has a societal impact as well.

6.2 Innovative supplementary heating system selection determinants

We have only a little information to compare and guide the start of this modelling. In Scarpa and Willis (2010), the energy saving component adds to the willingness to pay for a discretionary heating system. Also, in Lillemo et al. (2013) primary determinant for air-to-air heat pump investment is the desire to reduce heating costs. The consideration for variable costs *VarCostM* does in fact increase the chance of investing in an *InnoShs* by around 8% when we move up a category, so by over 30% in the tails.

The investment costs consideration lessens the percentage of having acquired *InnoSHS* by almost 7.2% per range. It can be that in making a big house purchase, the decision maker is cash-strapped and will pass on such an investment for the time being. While supplementary heating systems are considerably less expensive than primary heating systems, we are nevertheless talking a four-digit investment in euros at a minimum. Since these systems can be added later, it would be interesting to look into the possible adopters. At that point, it is also could be possible to benefit from domestic help credit, so investments into them might be deliberately pushed back.

The fact that people with a higher income do not seem to be more likely to invest in *InnoSHS* could be due to lack of full system automation. As supplementary heating systems in general are not as costly investment as the primary systems, we could be capturing effects of time valuation in various ways. Search costs for information as well as perceived additional operational need may present higher opportunity cost barrier. Indeed, when we tested with the inclusions of the *VeryBusy* variable, it seemed to lessen the selection slightly. It could also reflect the fact, that having *GrndHeat* makes household less likely to invest in a supplementary heating system at least in the start. Having an *Electric* heating system increases the probability, likely capturing air-source heat pump selection.

Scarpa and Willis (2010) find that information channels only have an impact if they are combined. In our survey, stating that the experiences of friends matter greatly negatively impacts supplementary heating system choice. It could be that there has been negative feedback on such solutions.

Table 11. Binary logit model for innovative supplementary heating choice.

Variable	Marginal effect	Standard error	Variable type
Age	-0.00216	0.00158	Metric
Female	-0.07458*	0.04004	No/Yes
Income	0.00502	0.01452	8 categories, cont
HighEdu	-0.00350	0.03961	No/Yes
Internet	0.08934**	0.04163	No/Yes
DHNet	-0.12603***	0.03857	No/Yes
GrndHeat	-0.21884***	0.04429	No/Yes
Electric	0.10805*	0.06039	No/Yes
Homesize	0.04950**	0.02209	5 categories
City	0.05887	0.04054	No/Yes
Remote	0.32861***	0.07289	No/Yes
HeatDgr	-0.15151***	0.03055	4 categories
InvCostM	-0.07180***	0.02469	Rating-scale 1-4
VarcostM	0.07953**	0.03365	Rating-Scale 1-4
NMental	-0.04606	0.05282	No/Yes
PosFrien	-0.08961**	0.03797	No/Yes
PoseLabl	0.08703**	0.04042	No/Yes
SelfSust	-0.06975	0.04381	No/Yes
Model fit			
Observations (n)			399
Parameters (k)			18
McFadden pseudo r^2			0.23
Correct predictions at 0.5			74.1%
Log-likelihood			-157
Restricted log-likelihood			-204

***, **, * = statistical significance at 1%, 5% and 10% level respectively.

The goodness of fit statistics at the bottom of table 11 indicate a fair model performance. The breakdown of the total correct predictions of 74.1% is that over 38% of the actual yes for *InnoSHS* and over 83% of the no options are correctly predicted.

Woersdorfer and Kaus (2011) study determinants of the interest to purchase a solar thermal system in Germany. The results do not speak strongly in favour of future adoption. The would-be purchasers are driven mainly by environmental attitude strongly influenced by peer group behaviour, but both the model fit and statistical impact of their research are moderate. On the contrary, in our sample being classified an environmentalist does not increase the *InnoSHS* adoption rate.

In an exciting deviation from discipline norms, it would seem that people who are willing to tap into the network want to be more interconnected. First of all, the use of the *Internet* is a positive predictor. The statement that the heating systems need to be as self-sustaining as possible (*SelfSust*) is a negative predictor although not with statistical significance. The same sign holds when we only test for solar-based supplementary heating systems, although with too few observations to conclude it. The readings from our data suggest that detached house owners who wish to be as self-sufficient as possible go with the ground heat option, which does not benefit similarly from supplementary heating systems. People living in the *remote* region are 32% more likely to invest in a supplementary system. In the very remote areas, it is plausible that the security of supply element may come into play. We argue this also shows the desire to be interconnected. Remote areas do have more future investment needs in the grid and already higher distribution prices. So, it makes sense that *VarCostM* increases the selection probability.

The variable *HeatDgr* gets a negative sign. Moving one category toward north lessens the likelihood of investing in an *InnoSHS* by about 5% for each step. The move from southern to northern parts adds up to 20%. It can reflect the innovation diffusion framework. More likely though, there is relatively more intensive *WoodSHS* use as we go north. We discover that the impact is reversed if we study the determinants of wood-based heating systems *WoodSHS* as a dependent variable. For such a regression, *InvCostM* and *HeatDgr* were the two determinants that positively predicted wood-based supplementary heating system choice, both with about 5% increase for the likelihood per range.

6.3 Primary heating system selection determinants

In existing research, richer, younger and more educated are more likely to go for a hybrid method. Technical limitations of the home do play a role. Regional differences exist reflecting different costs, tradition and available network between regions. Environmental awareness has an impact. Financial grants are also shown to make a difference. There is also evidence that homeowners may not be considering the entire lifetime cost profile when making their decision. (Michelsen & Madlener, 2012.)

In the newly built home subsample of Michelsen and Madlener (2012), the options are gas, heat pumps and wood pellet heating. The newly built home results mirror full sample analysis, but heating-system specific attributes are relatively more important. Similarly, as in their full analysis, there are statistically significant results found at the level in all categories in our formulation.

In Multinomial logit, β interpretation is through the utility dependence level on the β_{jk} of variable X_i relative to the base-category alternative probability. The base category in our model is *Electric*, the probability of which at mean values is 11.5%. Therefore, the estimated coefficient model βs normally have no intuitive interpretation, since they should be interpreted in relation to the chance for this likelihood. When we list marginal effects, we can measure the probability change in choosing the said system. Other probabilities in reported order are 1.4%, 66.8%, 5% and 15.3%. When we have a categorical variable, the reported marginal effect indicates a one-category shift. We decide to report the marginal effects at the means. Our results are summarized in table 12.

The goodness of fit statistics are given at the bottom of table 12. In this multinomial formulation, the estimated log-likelihood function at the maximum is compared to the restricted log-likelihood of an equal choice shares across alternatives model (no coefficients, zero slopes model). This tests if our model prediction is an improvement over the restricted model. The pseudo R^2s are considerably lower than linear R^2s. McFadden (1977) calls a pseudo R^2 value between 0.2–0.4 to represent an excellent model fit. One should note that the measure used here is not an adjusted one, so it does not punish for extra parameters. (Hensher et al., pp. 337–339.) Akaike information criteria of $-2(LL - k)$ does penalize for adding more parameters k. We use it as one tool to assist in selecting the most fitting model. (Akaike, 1974.)

Table 12. Multinomial logit partial effects at means.

Variable	*Electric*	*Wood*	*Grndheat*	*Dhetc*	*Heatpump*
Income	0.00402	-0.01183*	0.05651*	-0.02006*	-0.02864
Age	0.00225	-0.00031	-0.00378	-0.00170*	0.00354*
Homesize	-0.13156***	0.00501	0.18894***	0.01532	-0.07771***
Highedu	0.00073	-0.01249	-0.01033	-0.02920	0.05129
DHNet	-0.10953**	0.01753	-0.02157	0.18532***	-0.07175
InvCostM	0.12731***	-0.00045	-0.35096***	0.05054**	0.17356***
VarCostM	-0.13833***	0.01404	0.27927***	-0.01771	-0.13726***
ComfortM	-0.04579	-0.02689*	0.38006***	-0.09990***	-0.20749***
EnvironM	-0.05178*	0.01256	0.08687*	0.02596	-0.07359**
SelfSust	-0.09224**	-0.02202	0.18963**	-0.07712**	0.00175
HeatDgr	0.04183*	-0.00036	0.01630	-0.02698*	-0.03079
NoCoast	-0.04719	0.01459	0.13057	0.03512	-0.13309*
City	0.09695**	-0.02523	-0.10656	0.00023	0.03461
PosExp	-0.10487**	-0.02076	0.21383***	-0.02698	-0.06152
Exhibit	-0.04626	0.00317	0.10619	-0.03284	-0.03027
ElpricUp	-0.11724***	-0.00682	0.07164	0.00519	0.04724
Internet	0.00818	-0.02543	0.01707	-0.0602*	0.06042
ColdOK	0.10442**	-0.01373	-0.0548	-0.09564***	0.05962
LowEnerg	-0.06663*	-0.00494	0.15614**	-0.01658	-0.06800
VeryBusy	-0.13070**	-0.02306	0.15514**	-0.01085	0.00947
OwnWood	-0.00991	0.00836	-0.07631	0.01423	0.06364
Model fit					
Observations (n)					392
Parameters (k)					88
McFadden pseudo r^2					0.41
Akaike Information Criteria					811
Log-likelihood					-317
Restricted log-likelihood					-537

***, **, * = Statistical significance at 1%, 5% and 10% level respectively.

We start by looking into socio-demographic variables. We debated the inclusion of *Income*. As usual, it is the variable most often left unanswered. We decided after some deliberation to include it in this formulation according to the industry norms. The lone statistically significant impacts is a 5.6% effect on *GrndHeat* selection and a 1.1% drop for *Wood* as income grows. The averaged interpretation relates to a shift from middle of the range to the next so for instance from 3000 to 5000. The 8-range distance from lowest to highest income range suggests that above 14000 euros monthly family income raises the probability of selecting *GrndHeat* by almost 50% compared to if the monthly family income is below 2000 euros. In Braun (2010) and Michelsen and Madlener (2012) higher income makes it more likely that the household chooses gas.

The age of the decision maker is only significant for when the decision maker gets older, they become 0.35% more likely per year to choose *HeatPump,* and slightly less likely to choose *DHetc*. Higher education lessens the likelihood of choosing *Wood.* Here we will want to separate university and polytechnic-educated for further testing. Having own wood supply, *OwnWood,* increases the probability to choose *Wood* but only slightly. Here our choice not to impute missing observations leads to the loss of statistical significance. The same happens with *PosWood*. For some reason, wood-heating system owners are far more likely to leave some question in the questionnaire without an answer.

Moving onto house-specific characteristics, the smaller the home. the more likely it becomes that households choose either *Electric* or *HeatPump*. A smaller house could mean a smaller plot of land, making *GrndHeat* not viable. Naturally, the total variable costs also increase as the size of the heated floor space increases. The statistically highly significant impact of *HomeSize* reaches 18.9% for *GrndHeat* per mid-category shift. Having a -30% or more stringent energy standard home, *LowEnerg*, also increases *GrndHeat* likelihood. This is comparable to Michelsen and Madlener (2012). While in binomial analysis *DHnet* decreases the likelihood of choosing ground source heat pump, it does not do seem to do it at the expense of any other system. The impact of *DHnet* is just an 18% likelihood increase for district heating and others category *DHetc.* We note that having a renewables-based primary heating system would have bypassed any city plan ordering joining district heating network. Electric heating, however, would not have been accepted under those regulations. Coincidentally, we do find a statistically significant impact lowering the odds of choosing *Electric.*

For geographical variables, we start with *HeatDgr.* As we go north, it becomes relatively more likely that *Electric* is chosen. It is logically at the expense of *HeatPump* and also *DHetc*. Moving away from the coastline, *NoCoast*, it becomes 13% less likely that a household decides to choose *HeatPump*. Rural-urban divide manifests in increased prevalence of *Electric* heating systems in the cities. This is at the expense of *GrndHeat* and could reflect difficulties in getting a permit. It might also be in response to price expectations. In Asplund (1984), urban long-run electric heating use price elasticity is lower than in the countryside.

Finally, we are moving onto RHS-specific variables. The impact on the choice of the importance perception of investment cost *InvCostM* is quite large. The shift is sharply away from *GrndHeat* and into *HeatPump* and *Electric*. The variable costs component *VarCostM* is logically reversed. We noted in the binomial analysis of *GrndHeat* that it is evident that some financial constraints either due to credit issues or behavioural effects led homebuilders to select a cheaper heating system at the expense of future costs.

Michelsen and Madlener (2012) find no subsidy-impact among individuals who have just built a new house. Technical details are more important among them than economic issues. In Hecher et al. (2017), those in a new-building situation are more likely to care about the technical feasibility of the heating system than economic considerations. Therefore, the authors recommend actions to educate about the technical feasibility and long-term economic advantages of renewables. For our sample, we cannot conclude that technical details would play a more prominent role.

In Michelsen and Madlener (2012), those who seem to value the comfort of use more are more likely to choose gas, arguably a simpler system to operate than their other two options. For our analysis, a higher *ComfortM* impact on heating system choice very strongly drives the selection of *GrndHeat,* 38% increase at means and 25% averaged over individuals per each shift up the 4-scale Likert-like variable. On the contrary, it lessens the probability of selecting another type of *HeatPump* by 20%. Also, very understandably, it reduces the *Wood* selection attractiveness.

Asking how important environmental friendliness (*EnvironM*) is does not have a very large impact on heating system choice. It increases the choice probability of ground source heat pump at the expense of electric heating and district-heating group, but by single-digits per one category shift. Surprisingly, environmental considerations seem to have a relatively smaller impact than costs and comfort of use.

In assuming potential benefits from selecting environmentally friendly solutions and subsequent designing of policy tools, we need to take the so-called rebound effect into account. This term refers to the observation that people who choose a more environmentally friendly option may end up consuming more thus offsetting some or all the gains. They may either consume more of the good in question directly or indirectly permit themselves to consume something else instead. (Ruokamo, 2019 pp. 19–20.)

Interestingly, the respondents stating that information from experts is important to them raises the possibility of selecting *GrndHeat* quite a lot and lowers it for the rest of the systems, especially for *Electric*. However, receiving information on the heating systems from experts did have explanatory power. The same applies to variables *Friends* and *PosFrien*. Some people are more receptive than others per each information channel.

There is, however, one source of information that people use that seems to be linked with the heating system choice. This is the *Internet*. We know that a big portion of consumers seek information online prior to purchase. We also know that what consumers see in their online search can be impacted commercially and with other means of user profiling. It decreases the probability of selecting *DHetc* by 6% and *wood* by 2.5%. The same can be expected to be true for *Exhibit.* Going to a housing fair makes less sense after home has been built. It seems to increase *GrndHeat* selection to some degree.

The variable *ColdOK* enhances the *Electric* choice probability by more than 10%. We observe almost a similar magnitude negative impact on *DHetc*. It is clear that *DHetc* is much harder to adjust quickly and without any hassle.

Finnish people seem to have a strong desire for self-sufficiency. It is driving them towards the choice of *GrndHeat*, and away from *Electric* and *DHetc*. Declaring a hectic lifestyle (V*eryBusy*) shows expected sign to decrease the probability of selecting *Wood* and *Electric*, though the impact is large in magnitude only for *Electric*. The probability of *GrndHeat* selection increases by 15%.

The fact that rising electricity price expectations have impacted the choice of *Electric* heating negatively validates a similar finding from Sahari (2019). Our research suggests that the shift is toward ambient-electricity co-generation. Generally, house-specific and RHS-specific attitudes seem to play a bigger role than the geographical area and socio-demographic variables.

Hausman test presented in section 4.3 is used to test the multinomial logit model IIA-assumption in our model. We first run the original regression, (remembering that the first option parameters vector $\hat{\beta}_1$ is our base option) and store the full model unrestricted β-results vector $\hat{\beta}^u = (\hat{\beta}_2, \dots, \hat{\beta}_J)$ and the variance-covariance matrix $[Var\,(\hat{\beta}^u)]$. Following that one of the options will be dropped from the model and the resulting restricted-model estimates vector in $\hat{\beta}^r = (\hat{\beta}_2, \dots, \hat{\beta}_{J-1})$ and matrix $[Var(\hat{\beta}^r)]$ will be saved. We then compute the test-statistic following equation (8). (Cheng & Long, 2007.) Importantly Hausman and McFadden (1974) note that a negative test result leads to the conclusion that IIA holds.

Since we do not have alternative specific variables besides the constant, we compare the βs for all the sample variables to test whether IIA holds in each pair. With *GrndHeat* as an irrelevant alternative, we obtain Hausman Statistics value H of 25.92 and the p-value Prob>H of 0.99999978. This value is not critical, quite the contrary, so we cannot conclude that the null hypothesis of IIA does not hold. The remaining test in this formulation yield a negative H-value. In absolute terms, they are -109 for *Electric*, -2.4 for *HeatPump,* -37 for *Wood* and -286 *for DHetc*. For these options, the $\left[Var\left((\hat{\beta}^r\right) - Var\,\left(\hat{\beta}^u\right)\right]$ difference matrix is not positive semidefinite. Following Hausman and McFadden (1984), we state that IIA hypothesis cannot be rejected in these cases either.

We have carefully considered our modelling approach to include sufficiently distinctive categories of alternatives. Our bivariate analysis, which shows a similar profile, also lends further credence to the veracity of our results. We do, however, acknowledge that the tests for IIA-assumptions are problematic. Difficulties arise because the tests are so sensitive to the slightest of changes in sample size and number of parameters. The sum vectors grow bigger as parameters are added. If we happen to introduce parameter correlation, we cause problems. Being able to conclude with certainty that IIA-assumption holds in our sample will require some further investigation. The most critical question we can see a reader asking if the category *HeatPump* is discernibly different from *GrndHeat.* We do argue that they are. Across multiple formulations that we have tested, the most critical Hausman test value we have gotten is 63.65 with a p-value of 0.4745. At no point have we gotten a test result that would have led to the rejection of the IIA hypothesis. With fewer parameters and conversely more observations, the absolute values grow smaller. We note that even if IIA-condition was violated, we had already gotten information from bivariate analysis indicating that these results are still relevant. (Cheng & Long, 2007.)

Finally, here are comments from the survey pertaining to the satisfaction post-decision excluding *GrndHeat*, which was covered in section 6.1. Wood heating seems to split people from the middle. Many of those who use it praised its functionality. Others went as far as to suggest a Pigovian tax for it and complain of emissions from others. In total, about 20% of those who have the system, say their wood-based heating could use some improvements.

The air-to-water heat pump (50%) and the exhaust-air heat pump (29%) have a very substantial portion of users who say their system needs some improvements. Mostly, these include higher than expected electricity use. It becomes very evident from the multitude of answers that settings are problematic. Some users had them adjusted multiple times. It would seem this has a marked effect on the actual consumption and existing owners could benefit from settings check-up. We read suggestions that some market players do not know what they are selling. The system adjustments had been incorrect. A wrong sized pump will not work perfectly. The slow speed of reaction is noted most frequently by air-to-water heat pump users. There are also several positive comments regarding the cost of operation.

Some respondents harshly critique the fixed-fee payment associated with district heating that is due each period. It is the main contributor to the 23% rate for those who feel their system needs improvements in this group. The in-house control difficulty is the other issue. Two respondents state they were forced into the system by the city. Comments include that the companies will not have incentives to cut emissions because they can for instance move the costs of emission rights straight to the customers in the future. The system improvement requirements from 17.7% of electric storage heating adopters are related to costs and the desire to have larger warm water storage. Direct electric heating improvements were desired by 32%. These were mostly about the variable costs. There are people who clearly got surprised to learn how big the variable costs are for electric heating.

7 SUMMARY

The purpose of this thesis is to examine the determinants of residential heating system choices. We run separately binomial logit analysis for the determinants of ground source heat pump and the innovative supplementary heating systems selection. Moreover, with a multinomial logit model, we study the impact of socio-demographic, house-specific, geographic and heating-system specific variables on the choice of five distinct heating alternatives— ground source heat pump, electric heating, wood-based heating, other heat pumps and district heating plus other systems categories.

The most significant determinants to increase ground heat choice probability are the desire for a comfortable system, building a big home and the importance of variable costs when choosing the heating system. The positive expert opinion and the desire to have a self-sustaining heating system also increase the selection probability. Investment costs importance being huge negative determinant suggests that we have groups of homebuilders who would have chosen this system if it had been financially possible. In this point, our research aligns with findings from intention to adopt study by Karytsas and Theodoropoulou (2014).

For supplementary heating choice, the result we get is that wanting to have as self-sustained a heating system as possible slightly diminishes the likelihood of choosing innovative supplementary heating system. Instead, our research would seem to implicate that the people who invest in such a system wish to remain interconnected with the grid. The fact that they are also more likely to search for information from the internet further corroborates this view. People living in a remote area are more willing to add a supplementary heating system.

Making a big investment in a detached house can mean having to skimp on further purchases. Investment costs consideration does contribute to the innovative heating system adoption decision negatively. It is also possible that the absence of domestic credit help tax rebate from a new home building situation pushes additional heating investments into the future. The importance of energy performance certificate most likely captures the effect of augmenting electric heating choice with an air source heat pump. This indicates that energy performance certificate does impact innovative supplementary heating system choice. Having electric heating also increases the likelihood to some extent.

Analogous to Sahari (2019), in our multinomial analysis we discover that expectations of rising electricity prices drive people away from electric heating. However, we have no evidence that this shift is towards non-electricity using systems. Unlike Sahari, we did not separate electric storage heating and direct electric heating in this regard. We make a general point that as electricity price becomes more lump-sum based, incentives to choose more energy-efficient systems go down. A survey respondent poins out that similar disincentive can be true with respect to district heating utilities. If they charge more fixed-fee based, consumers face a lower marginal price per unit. The utilities could more easily substitute emission trading rights prices with the lump sum. It in turn lowers their incentives to clean up production.

The determinants of ground source heat pump differ considerably from air-to-water and exhaust-air heat pumps. Investment costs impact their selection in the opposite direction. Our analysis suggests that one should not pool ground source heat pump with other pumps in the Finnish market, something that existing research such as Michelsen and Madlener (2012) has done. Out of all the information channels, expert opinions are the most important contributor on heating mode selection. The shift is away from electric heating to ground source heat pump. We also find differences between system adjustment preferences. Wanting to be able to adjust the system with ease increases electric heating choice probability.

Our survey discovers that users are considerably more likely to find some areas for improvement in heat pumps. Post-sales services are required. They could also benefit from product development that makes temperature control more fluid and quicker to react. In line with Hecher et al. (2017), we also find considerable differences in consumer preferences. This is especially pronounced when it comes to the use of wood in heating and the related daily activities that it entails.

In the future, we could study how households' actual choices are reflecting in the choice-experiment data presented in Ruokamo (2016). Few studies exist on considering primary and supplementary heating system choice simultaneously.

Michelsen and Madlener (2012) find that for existing homes, the previous heating system strongly predicts the new retrofit choice. Since previous heating-system has strongly predicted heating system retrofits, it would be of interest to know how much previous system operation experience impacts the choice for a new home as well. In Lillemo et al. (2013), aesthetic displeasure with the existing heating pump considerably decreases the likelihood to reinvest in one. Such a subjective category could be studied.

Limitations of the study include the response rate of 21.6%. While it is on the good side in the field, it could have been higher. The relatively low percentage of wood-based choices makes those results in multinomial logit model somewhat less precise and statistically less significant. It is especially true absent imputing missing observations, where more wood heating owners left questions unanswered. Across the entire survey, around 14% of the papers have at least one missing answer. Getting this lower could be possible. We will also further continue to study how our formulation of the problem can be augmented.

Most significant determinants in our analysis are RHS-specific and house-specific details. By order of magnitude, environmental considerations are not as crucial to the decision makers as cost and comfort. Policy instruments are therefore necessary. We emphasise, that any such instruments should not look at heating markets as a homogenous entity but instead pay attention to the heterogeneity among decisions makers.

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